Conservation perspectives at Lake Alaotra, Madagascar – ecological state, nature protection and resource use

Dissertation

zur Erlangung des akademischen Grades

Doktor der Naturwissenschaften (Dr. rer. nat.)

Schwerpunkt Biologie

Fachbereich 4

Universität Hildesheim

Institut für Biologie und Chemie

vorgelegt von

Pina Lena Lammers (M.Sc)

geboren am 13.02.1984 in Lengerich

Gutachter 1: Prof. Dr. Jasmin Mantilla-Contreras (Universität Hildesheim)

Gutachter 2: Jonah Ratsimbazafy (Universität Antananarivo)

Tag der Einreichung: 03.12.2018

Tag der Disputation: 28.02.2019

„Die Natur muß gefühlt werden, wer sie nur sieht und abstrahiert, kann … Pflanzen und Tiere zergliedern, er wird die Natur zu beschreiben wissen, ihr aber selbst ewig fremd sein.“

Alexander von Humboldt (1769 - 1859)

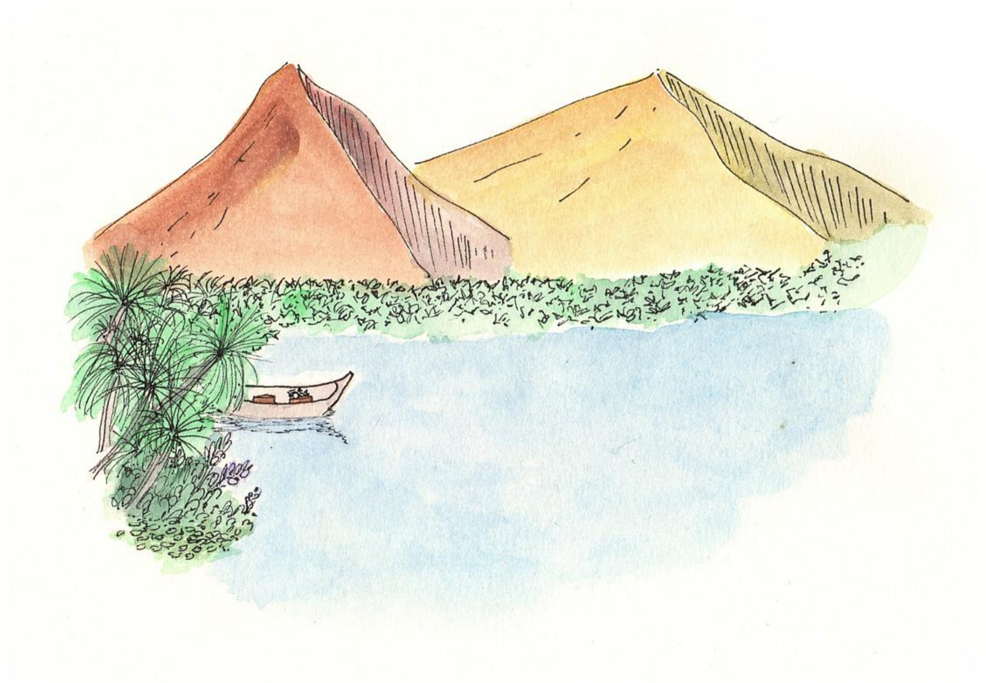

Table of Contents

Summary

Tropical wetlands maintain a high biodiversity and provide ecological services which are basis for millions of livelihoods. However, freshwater ecosystems are largely neglected in research and environmental policy. Today they are among the most threatened habitat types throughout the world with highest loss rates for natural inland wetlands in the tropics. The high dependency of local communities upon natural resources makes conservation management for wetlands in developing countries to a particular challenge.

This study investigated the different perspectives of conservation planning at Lake Alaotra, the largest wetland complex of Madagascar. First, the ecological state of Lake Alaotra was assessed to close knowledge gaps and to provide an adequate basis for ecosystem-based conservation measures. Second, I evaluated the community-led management of a small protected area in order to determine its potentials and weaknesses. Third, the local fishery, as the largest lake resource user group, was investigated to understand the drivers of overfishing.

By interlinking the results of the three perspectives of conservation planning – ecology, management and resource user – interrelations and trade-offs between the three dimensions were identified. The current ecological state of Lake Alaotra reveals that the anthropogenic disturbance is favoring the proliferation of invasive plant species and leading to the alteration of the water quality (e. g. hypoxia). Insights into the local management show that the community-based management contributes to the conservation of the natural flora and fauna. However, the small-scale conservation area suffers from isolation and illegal activities, while its management lacks recognition at community level. The fishery sector has grown dramatically although fish catches have fallen sharply. Species composition changes and low reproduction rates are reflecting the fishing pressure. A high population growth and lacking agricultural land force people to enter fishery and increases the human pressure on the lake.

Overall this study shows that the conservation of multiple-value ecosystems, such as tropical wetlands in developing countries, require site-specific multidimensional approaches that interlink ecological demands, resource user needs and the local sociocultural setting. This research demonstrates that: ongoing livelihood dynamics linked to the socio-economic conditions have to be considered to create more realistic management policies; strengthening resource users' assets will help to decrease the human pressure on the already considerably altered ecosystem; capacity building for local management associations and the adoption of local ideas and management concepts is needed to enable the evolvement of an locally legitimated and tailored wetland conservation management.

Zusammenfassung

Tropische Feuchtgebiete weisen nicht nur eine einzigartige Biodiversität auf, sondern bilden auch die Lebensgrundlage für Millionen von Menschen. Süßwasserökosysteme werden jedoch in Forschung und Umweltpolitik weitgehend vernachlässigt. Heute gehören sie weltweit zu den am stärksten bedrohten Lebensraumtypen mit den höchsten Verlustraten für tropische Binnenfeuchtgebiete. In Entwicklungsländern ist ihr Schutz aufgrund der hohen Abhängigkeit der lokalen Bevölkerung von den natürlichen Ressourcen eine besondere Herausforderung.

Diese Studie untersuchte die verschiedenen Perspektiven der Naturschutzplanung am Beispiel des Alaotra Sees, dem größten Feuchtgebiets Madagaskars. Hierzu wurde der ökologische Zustand des Alaotra Sees bewertet, um eine geeignete Wissensgrundlage für der Naturschutzplanung zu schaffen. Das örtliche Management eines kleinen Schutzgebiets wurde evaluiert, um dessen Potentiale und Schwächen festzustellen. Um die Gründe der Überfischung zu verstehen wurde die lokale Fischerei als größte Nutzergruppe der Seeressourcen untersucht.

Durch die Verknüpfung der Dimensionen der Naturschutzplanung, Ökologie, Management und Ressourcennutzung, konnten Zusammenhänge und Zielkonflikte zwischen diesen identifiziert werden. Der ökologische Zustand des Alaotra Sees zeigt, dass der anthropogene Einfluss die Verbreitung invasiver Pflanzenarten begünstigt und zu einer Abnahme der Wasserqualität führt. Einblicke in das lokale Management zeigen, dass das kleinflächige Naturschutzgebiet zum Erhalt der natürlichen Flora und Fauna beiträgt, jedoch unter Isolation und illegalen Aktivitäten leidet, während es dem Management an Legitimierung mangelt. Der Fischereisektor zeigt ein dramatisches Wachstum – trotz des starken Rückganges der Fangerträge. Änderungen in der Artenzusammensetzung und niedrige Reproduktionsraten belegen den Fischereidruck. Hohes Bevölkerungswachstum und mangelnde Agrarflächen zwingen die Menschen zum Eintritt in die Fischerei und erhöhen den anthropogenen Druck auf den See.

Insgesamt zeigt diese Studie, dass die Erhaltung von Ökosystemen mit vielfacher Bedeutung, wie die tropischen Feuchtgebiete der Entwicklungsländer, ortsspezifische mehrdimensionale Ansätze erfordert, die ökologische Anforderungen, die Bedürfnisse der Ressourcennutzer und das lokale soziokulturelle Umfeld einschließen. Diese Studie zeigt, dass Veränderungen der Lebensgrundlagen und die sozioökonomischen Bedingungen berücksichtigt werden müssen, um realitätsnahe Managementstrategien zu schaffen; dass die Stärkung der Rücklagen der Ressourcennutzer dazu beitragen kann, den anthropogenen Druck auf das Ökosystem zu verringern; dass der Kapazitätenaufbau für lokale Managementverbände und die Übernahme

lokaler Ideen und Managementkonzepte erforderlich sind, um die Entwicklung eines lokal angepassten und legitimierten Managements zu ermöglichen.

Chapter 1

GENERAL INTRODUCTION

1.1. Biodiversity and nature protection in developing countries

Global biodiversity is exceptional high in the tropics with most of the biodiversity hotspots (see Figure 1.1.) located in developing countries (Myers et al. 2000, Brown 2014). Today, world’s biodiversity is undergoing a continuous, rapid decline (Myers et al. 2000, Butchart et al. 2010, Mittermeier et. al. 2011, Ceballos et al. 2017). While causes of former extinction events are still under debate – the current loss, considered as the ‘sixth mass extinction’ in the earth’ history, is undeniably human-made (Barnosky et al. 2011, Pievani 2014, Ceballos et al. 2015). Human population growth and overconsumption are the ultimate drivers of a multitude of factors causing biodiversity loss: habitat loss and fragmentation, a changing global climate, chemical pollution, overexploitation of resources and introduction of non-native species. However, these factors do not only threaten biodiversity but also ecosystem services and human wellbeing (Barnosky et al. 2011, Pievani 2014, Ceballos et al. 2015). In a time where “*human modification of the global environment had become significant enough to warrant termination of the current Holocene geological epoch and the formal recognition of a new ‘Anthropocene’ epoch*” (Smith and Zeder, 2013, p.1) the implementation of conservation measures and the examination of weaknesses in current management approaches is more important than ever. This is especially true for developing countries. Nevertheless, in those parts of the world a rapid human population growth, political instability and poor law enforcement, poverty, low literacy rates and poor infrastructure make nature conservation to an onerous mission (Barrett et al. 2001, Fisher and Christopher 2007, Giam et al. 2010, Tscharntke et al. 2012, Laurance et al. 2014, Mbiti 2016, UNDP 2016).

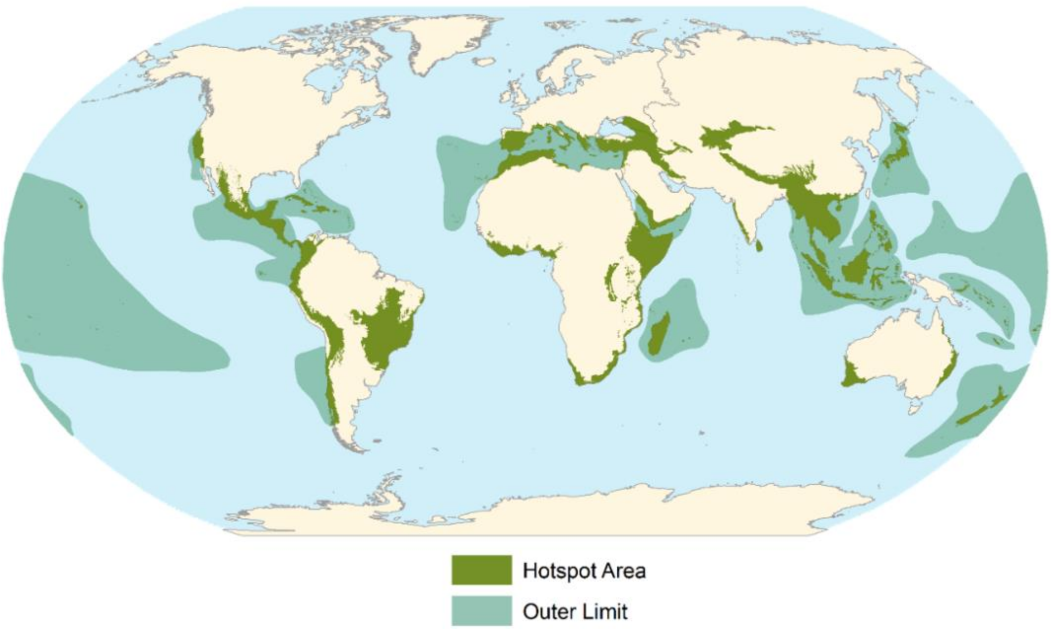

Figure 1.1. Global biodiversity hotspot distribution: areas with the most unique biodiversity that are simultaneously experiencing high rates of habitat loss (Conservation International 2011).

To overcome the gap between the prevailing conditions and to pursue the need for biodiversity protection, tropical biodiversity conservation has undergone a radical shift during the last decades. As a result, a variety of new conservation approaches have emerged. Those, however had all one common goal: to drop the previously common top-down policy in favor of bottom-up approaches. The new approaches should emanate from the local communes and avoid the „*real or perceived government malfeasance, misfeasance, or nonfeasance under the previous top-down model*" (Barrett et al. 2001, p.497).

1.2. Conservation perspectives in the developing world – finding the inherent conservation identity

What was the intention behind the radical shift in tropical biodiversity conservation from policy to a people-oriented management? As in most of the tropics nature conservation in Africa in the 20th century was largely shaped by the interests and perspectives of the developed countries and enforced top-down by national or international governments and conservation organizations (Barrett et al. 2001, Abrams et al. 2009, Sodhi et al. 2011). The frequent failure of those conservation incentives can be basically explained by contrasting socio-economic priorities: while developed countries might aim for a steady-state economy incorporating a zero-population growth, developing countries are likely to continue to expand their economies to alleviate poverty (Barrett et al. 2001, Czech 2008, Roe 2008, Kerschner 2010, Brooks et al. 2013, UNDP 2016, Fosu 2017). Poverty which is mainly manifested in hunger affects major parts of the developing world's population. 80% of the people facing food insecurity live in rural areas of the developing countries, half of them are smallholders (Snel 2004, Elvidge et al. 2009, Tscharntke et al. 2012). In this context Sodhi et al. (2011, p. 522) emphasized that "*All conservation initiatives should be sensitive to existing interactions that are of key importance for the lives of local people, who are and will remain the primary stakeholders in the conservation of their landscapes and biodiversity*." Biodiversity conservation in developing countries therefore needs to incorporate local socio-economic targets of agricultural growth based on smallholder farming (Fisher and Christopher 2007, Roe 2008). As the realization of conservation policies takes place at the local level, the bottom-up approach allows to be more attentive to local conditions shaping nature-people interactions: vested interests and needs of stakeholders, their experience of, and attitude towards conservation as well as their educational and institutional backgrounds; existing local tradition and culture, social norms and hierarchies (Fabricius 2004, Pietrzyk-Kaszyńska and Grodzińska-Jurczak 2015, Molotoks et al. 2017). By seeking local stakeholders' participation, the bottom-up concept promotes community capacity-building (individual, social, institutional) and initiative for developing solutions tailored to local conditions and hence contributes to project continuation beyond time of funding (Freebairn and King 2003, Fraser et al. 2006b, Hewitson 2015, Aguiñaga et al. 2018). Further advantages of this approach are the rapid detection of, and reaction to unpredicted changes affecting the local environment (e.g. social conflicts or natural disasters) which facilitate a more flexible and adaptive management and the community's traditional ecological knowledge which helps to offset missing data on local ecological conditions, common in the tropics (see Fraser et al. 2006a, Barber et al. 2014, Pietrzyk-Kaszyńska and Grodzińska-Jurczak 2015). Altogether, the anticipated improvements in tropical biodiversity conservation should result in (i) a more equal distribution of conservation benefits due to an increased transparency and internal control, (ii) a higher commitment to conservation targets and practices by local populations and (iii) thereby maximize the usefulness and the prospects of conservation management (Barrett et al. 2001, Fabricius 2004, Roe 2008). Though promising in theory, bottom- up nature conservation approaches have to contend with numerous problems in practice (e.g. financial mismanagement, conflicts, mismanagement of natural resources, lacking human capacities and divergent interests; cf. Blaikie 2006, Fabricius and Collins 2007, Brooks et al. 2013) whose detection and evaluation are posing new challenges to nature conservation in developing countries.

Today, paying attention to the ecological, social and economic dimensions is not only seen as a key prerequisite for nature conservation but is also internationally recognized to be fundamental for sustainable development policy (Maes et al. 2014, United Nations 2015). In this context, bottom-up participation has become worldwide an important tool to select relevant local indicators for management frameworks since the socio-economic and environmental settings locally differ far beyond the tropics (Pretty 1995, Fraser et al. 2006b, Eckerberg et al. 2015, Neugarten et al. 2016, Aguiñaga et al. 2018).

1.3. The case of Madagascar – one of the hottest biodiversity hotspots worldwide

Madagascar clearly illustrates the importance of incorporating social and economic aspects into nature conservation planning. The country is of critical priority within international conservation efforts (Brooks et al. 2002, Goodman and Benstead 2005, Giam et al. 2010). Due to its early isolation in earth history (65.5 million year ago) and its high variety of landscapes and climatic regions Madagascar has an exceptionally high biodiversity and level of endemism (Yoder and Nowak 2006, Vences et al. 2009). 52% of the islands' birds, 65% of the freshwater fishes, 86% of macroinvertebrates, 92% of reptiles, more than 90% of the Malagasy plants and

100% of the native amphibian as well as terrestrial mammals exclusively occur on Madagascar (Goodman and Benstead 2005, Vences et al. 2009). This unique biodiversity, however, is highly threatened due to extensive habitat loss and degradation (Harper et al. 2007, Ganzhorn et al. 2001).

The Malagasy populations dependence on subsistence agriculture, fuelwood cutting (85% of the Malagasy population rely on charcoal for cooking) and the widespread use of slash and burn practices (known as '*tavy*') lead to soil erosion, deforestation, overgrazing, desertification, and water pollution (Harper et al. 2007, Nellemann et al. 2014, Máiz-Tomé et al. 2018). Illegal logging and timber trade (e.g. of rosewood, *Dalbergia* spp.), wildlife trafficking (e.g. trade of the ploughshare tortoises, *Astrochelys yniphora*, and live capturing of lemurs to sell them as pets) and mining (e. g sapphire, ilmenite and nickel-cobalt mining) play also a significant role in species decline and environmental degradation (Duffy 2005, Froger and Méral 2012, Schwitzer et al. 2014, Virah-Sawmy et al. 2014, Borgerson et al. 2016, Gore et al. 2016, Reuter et al. 2017, Zhu 2017).

Peoples reliance on natural capital, common illegal practices as well as the negative environmental impact of extractive industries are embedded in a difficult and complex socio-economic and political setting. Madagascar's economy is based on subsistence agriculture, with 70% of the Malagasy population being farmers, mainly smallholders (Harvey et al. 2014). Especially in remote rural areas the population is subjected to food insecurity and there is few access to basic services, such as health care, clean water, electricity, and education (Larson et al. 2006, Harvey et al. 2014). Madagascar belongs to the poorest countries of the world. More than 80% of its population is living in poverty (World Bank 2014, Elvidge et al. 2009) with an annual per capita gross national income (GNI) of only 400 US$ (World Bank 2018a). In 2016, Madagascar was placed 158th out of 188 countries in the Human Development Index issued by the United Nations Development Programme (UNDP 2016). With a yearly growth of 2.7% the islands population exerts one of the highest growth rates worldwide and the population is expected to double until 2050 (World Bank 2018a, 2018b). Meanwhile, the country is suffering recurrent political instability coming along with political turmoil, corruption and clientelism. As a result, environmental policy is hampered by weak governance as well as poor law enforcement and compliance (Pollini 2011, Rakotomanana et al. 2013, Schwitzer et al. 2014).

Currently, Madagascar has lost most of its natural vegetation and many of its ecosystems are highly threatened, particularly tropical dry forests (Ganzhorn et al. 2001), littoral forests (Razafindraibe et al. 2013) and wetlands (Bamford et al. 2017). Simultaneously, biodiversity is shrinking at a high pace and many species are close to extinction (Young et al. 2014, Theisinger and Ratianarivo 2015, Máiz-Tomé et al. 2018). Madagascar’s endemic primates, the lemurs, are currently the most endangered mammals of the world (Schwitzer et al. 2014) At the same time an assessment of Madagascar's freshwater fish showed that even 85% of the endemic species are threatened (IUCN, 2004). However, whereas lemur taxa and their habitats are the focus of conservation efforts, freshwater ecosystems and their biota are largely neglected in research and environmental policy – even despite the fact that they do maintain a high biodiversity and provide ecological services which are basis for millions of livelihoods (Junk 2002, Rebelo et al. 2010, Gibson et al. 2015, Bamford et al. 2017).

1.4. The challenge of conserving Madagascar’s freshwater wetlands

Madagascar is rich in freshwater wetlands. About 2,000 km² of lakes and more than 300 km of rivers and streams are located in 256 catchments (Máiz-Tomé et al. 2018). Freshwater wetlands are rich in biodiversity and exhibit a high degree of endemism. Their high primary productivity, the diverse range of hydrological conditions as well as the insular nature of wetlands result in a high species turnover (*ß-diversity*) and a high proportion of species with a small geographical range, often restricted to one area (Gibbs 2000, Dudgeon et al. 2006, Strayer and Dudgeon 2010). However, freshwater ecosystems are among the most threatened habitat types throughout the world (Abell 2002, Carpenter et al. 2011, Holland et al. 2012). Overexploitation, invasive species introduction, water pollution, flow modification, habitat degradation and destruction have led to a faster and stronger decline of species in freshwaters than in marine and terrestrial ecosystems (Sala et al. 2000, Dudgeon et al. 2006, Strayer and Dudgeon 2010). Monitoring and conservation programs that focus on species of freshwater habitats are nonetheless comparatively rare, especially in tropical latitudes (Dudgeon et al. 2006, Bamford et al. 2017). For millennia, the fertile soils of tropical wetlands and the year-round available water have tempted people to settle down. Agriculture, livestock breeding, fishery and other ecosystem services support well-being of millions of people living nearby wetlands (Junk 2002, Rebelo et al. 2010, Gibson et al. 2015). Wetlands ‘health’ is based on a variety of ecosystem processes (*or functions*), whose disruption will subsequently alter ecosystem services. These functions are (i) water quality improvement by removal of nutrients, metals, toxic organics and sediment, and the transformation of nutrients, (ii) the provision of habitat for plant and animal communities, (iii) a high nutrient availability and primary productivity and (iv) sediment stabilization and reduction of erosion, ground water and aquifer recharge, storage of floodwaters, and maintenance of surface water flow during dry periods (Gibson et al. 2015, Mitsch and Gosselink 2015). Particularly tropical wetlands are imperiled to lose the balance between land use and ecological functions; the dependency of local communities upon natural resources and the human population growth is both highest in the tropics (Roe 2008, UN 2017).

So far, already more than 50% of coastal and inland wetlands have disappeared globally, of which 87% have been lost since the beginning of the 18th century. Although loss rates slowed down in some parts of the world (e.g. North America, Europe) the decline of wetlands continues in the tropics with highest loss rates for natural inland wetlands (Davidson 2014). In this regard Madagascar is no exception: Kull (2012) found out that 60% of the freshwater wetlands in the highland region have been lost. Bamford and colleagues (2017, p.1) confirmed in a recent survey of 37 lakes the "*profound and pervasive degradation of Madagascar's freshwater wetlands*" with 82% of the freshwater marshes being converted into agricultural land. Data on the islands freshwater biota and ecosystems are largely lacking; only recently, the first comprehensive assessment of the status and distribution of Madagascar's and the Indian Ocean islands' freshwater species was completed. This assessment found that nearly half (43%) of the whole freshwater biota is threatened to extinction while for almost one third (23%) of the species we lack information about their distributions and conservation and thus their status was set to 'data deficient' (Herrera 2017, Máiz-Tomé et al. 2018). As a consequence, there is an urgent need for studies and continuous data on Madagascar's freshwater ecosystems and biota to fill the gap of knowledge that impedes the prioritization of species and sites for conservation.

Until now, freshwater biodiversity is significantly underrepresented in the current Madagascar Protected Area System (SAPM), which comprises mainly forest ecosystems (Bamford et al. 2017, Benstead et al. 2003, Kull 2012, Máiz-Tomé et al. 2018). From the 122 sites integrated in the SAPM there are only few freshwater ecosystems (e.g. the wetland complex of Lake Alaotra, Mahavavy-Kinkony and Mangoky-Ihotry) (Rabarison et al 2015). One might be optimistic when considering the only recent declaration of ten more 'Wetlands of International Importance'[1] (in total 20 Ramsar sites) and the following increase of Ramsar site area to more than two million hectares (Ramsar 2018). But the past has shown that as long as humans entirely depend on natural resources and law enforcement is poor neither the status as Ramsar site nor

[1] The Convention on Wetlands of International Importance is an intergovernmental treaty that identifies wetlands of international importance (Ramsar sites). Ramsar sites have to fulfill/are designated based on the criteria of containing representative, rare or unique wetland types, and to be of international importance for conserving biological diversity. The convention provides an framework with a series of actions for national policy and international partners in order to achieve sustainable use of the wetlands and their resources for national.

the designation as new protected area could so far stop the progressive degradation of freshwater wetlands (Bamford et al. 2017, Gardner et al. 2018).

1.5. The Alaotra wetlands

The largest wetland complex of Madagascar is formed by Lake Alaotra (20,000 ha) and its adjacent marshes (23,000 ha) (Copsey et al. 2009a). The Lake Alaotra wetlands represent a multiple use site where human needs collide with biodiversity conservation and the maintenance of ecological functions.

More than half a million people live in the Lake Alaotra basin and depend on the high productivity of this area (Ratsimbazafy et al. 2013). The shallow lake stretches 40 km into the landscape and is home of the islands biggest inland fishery (Ferry et al. 2009). With the onset of the rainy season the surroundings become furthermore the country’s largest rice production area, yielding 300,000 tonnes rice per year on around 120,000 ha (Ratsimbazafy et al. 2013). Due to the region’s significant contribution to national economy it attracts immigration. During the last 20 years the region had the highest population growth rate of Madagascar with 4.2% per year (Bruelle et al. 2014). The high human pressure however, has resulted in a multitude of problems: overfishing and overgrazing, marsh burning and conversion into rice fields, the spread of invasive species, soil erosion, lake siltation and fuelwood cutting have left a highly degraded landscape and a fragile biodiversity (Andrianandrasana et al. 2005, Bakoariniaina et al. 2006). Today, the locally endemic Alaotran gentle lemur (*Hapalemur alaotrensis,* locally called ‘*Bandro*’) is among the 25 most endangered primates worldwide with less than 2500 individuals left (Ralainasolo et al. 2006, Schwitzer et al. 2017). Endemic waterfowl species are threatened (Meller´s Duck, *Annas melleri*), have entirely disappeared at Lake Alaotra (the Madagascar pochard, *Aythya innotata*) or even become extinct (the Alaotra Little Grebe, *Tachybaptus rufolavatus*) (Bamford et al. 2015, Razafindrajao et al. 2017). The local fish community has undergone significant changes due to various introductions and high fishing pressure (Wallace 2012). Since 1950 the marshes have already lost 70% of its size and remaining wetland vegetation is becoming increasingly fragmented and degraded (Riquier and Ségalen 1949, Ratsimbazafy et al. 2013)

Since the late 1980s efforts have been made to protect the wetland’s pristine biodiversity and integrity, namely by the Durrell Wildlife Conservation Trust (Andrianandrasana et al. 2005). Participatory approaches including e.g. ecological monitoring as well as the training of local tourist guides and awareness campaigns were conducted alongside to the elaboration of management plans and the establishment of the community-led ‘Park Bandro’ – a protected area of about 85 ha encompassing the largest remaining population of the Alaotran gentle lemur (Ratsimbazafy et al. 2013). Besides, the Alaotra wetland complex has increasingly drawn the attention of scientists. Nonetheless, livelihood dependence on natural resources, poverty and population pressure makes it tremendously difficult to enforce any kind of resource-usage restrictions which are necessary to secure the ecological and economic value of the Alaotra wetland complex. Moreover, research is mainly focused on the endemic Alaotran gentle lemur and agricultural practices, mainly on rice cultivation (e.g. Mutschler et al. 1998, Mutschler 2003, Guillera-Arroita et al. 2010, Penot et al. 2014, Bruelle et al. 2014). Huge gaps exist in basic knowledge on the ecological state of the lake and the surrounding marsh vegetation. The last comprehensive ecological study has been conducted 25 years ago (Pidgeon 1996). The missing data and the fact that the wetland system is undergoing huge changes, however, make it difficult to assess to which extend the anthropogenic pressure has already altered the ecosystem and to adapt conservation priorities and measures. Human dimensions of conservation (social and economic), which are decisive to understand patterns of resource use and failures in management are still poorly studied.

1.6. Insights into human perspectives – challenges for livelihoods in the Alaotra basin

Livelihoods at Lake Alaotra mainly depend on fishery and agriculture, primarily rice cultivation. Most of the farmers are smallholders, cultivating their fields traditionally, using animal traction and family labor (Ducrot and Capillon 2004). Similarly, the Alaotran fishery is characterized by family-based, small-scale, artisanal fishing activities. Fishers are operating family-based using dugout canoes and a wide range of traditional fishing methods and gear depending on the target species (cf. Wallace 2012, Breuil and Grima 2014). As the Alaotra region has a poor infrastructure (access to electricity, water, sanitation and health services are largely lacking and road conditions are poor) alternatives sources of income besides fishery and agriculture are rare. Low standards in education levels and lacking access to credit facilities moreover impede the development of new livelihood opportunities (Ducrot and Capillon 2004, Richter et al. 2015).

People in the Alaotra region had always to adapt to changes and to cope with seasonal shocks. While fishes can be caught year-round, farmers depend on rainfall in the rainy season. Rainfalls in the Alaotra region are however subjected to high inter- and intra-annual changes, making production cycle and harvest unpredictable and putting farmers to high production risks. In 1960, the hydro-agriculture development project SOMALAC (*Société Malgache d'Aménagement du Lac Alaotra*) started to install irrigation systems on 30,000 ha of rice fields that allowed regular and high yields. After the closure of SOMALAC in 1990 systems were poorly maintained leaving behind two third of those rice fields under poor water control (Saint-André et al. 2010, Mac Dowall et al. 2011). The resulting disenchantment of the Alaotran population were the origin of their general skepticism towards development projects (Mac Dowall et al. 2011, Rakotoarisoa 2018). Today, only 30% of the traditional lowland paddy fields are irrigated while 70% face a poor water control (Bruelle 2014).

Beside of the erratic rainfall pattern, demographic factors make livelihood security today to an ever-tougher challenge for the Alaotran population. Traditionally rice is grown on non-irrigated lowland plains during rainy season and followed by fallow periods (Mac Dowall et al. 2011, Bruelle 2014). The dramatic population growth has led to the lack of the cultivated lowland plains (locally called *vary taona*) and forced people to grow rice in the uplands, the *tanety* (hills). In this context of agricultural land limitation people were further obliged to intensify agricultural production on existing lands. A continuous tillage and reduction of fallow periods led to soil erosion and soil fertility losses and subsequent yield decline or stagnation (Mac Dowall et al. 2011, Bruelle et al. 2014). Subsequent attempts towards intensified and sustainable agriculture (introduction of the System of Rice Intensification (SRI) and Conservation Agriculture, respectively) failed due to famers low investment capacity and poor water control (Penot et al. 2014). In recent decades rice farmers have started to expand into the marshes for the cultivation of rice (so called *vary jebo*) in order to escape land limitation and rainy season dependent cultivation.

Although fishers benefit from daily cash income and a comparative independence from seasonality, they have to struggle with declining catches, resulting from overfishing, destruction of spawning sites, pollution and lake siltation due to erosion (Andrianandrasana et al. 2005). The wide distribution of mosquito net fishing, with high juvenile fish capture rates, amplifies the drop in catch levels. In 1960, 4000 tonnes of fishes were caught every year. Today annual catches have fallen below 1000 tonnes (Ratsimbazafy et al. 2013). The introduction of a two-month fishing closure (mid-November to mid-January) could not stop people to fish because of lacking livelihood alternatives and low financial reserves. Notwithstanding, few research has been done in order adapt management and secure fisher's livelihoods. First comprehensive investigations on fisher's behavior in 2009 and 2010 induced the implementation of spatial fishing closures at Lake Alaotra in order to reduce the socio-economic cost for fishers (see Wallace 2012).

1.7. Study aims

A multidimensional system such as the Alaotra wetland system where human livelihoods and the ecosystem health are inextricably entwined requires adapted conservation approaches. For this purpose, this study examined the different perspectives of conservation planning in order to overcome the barriers set by traditional biodiversity conservation approaches between the three dimensions (Figure 1.2.). In the past, the dimensions in conservation planning (ecosystem, resource users and management) were considered separately and with one-directional interrelations. Following, top-down conservation management was rather oriented towards ecological settings than socio-economic needs of resource users.

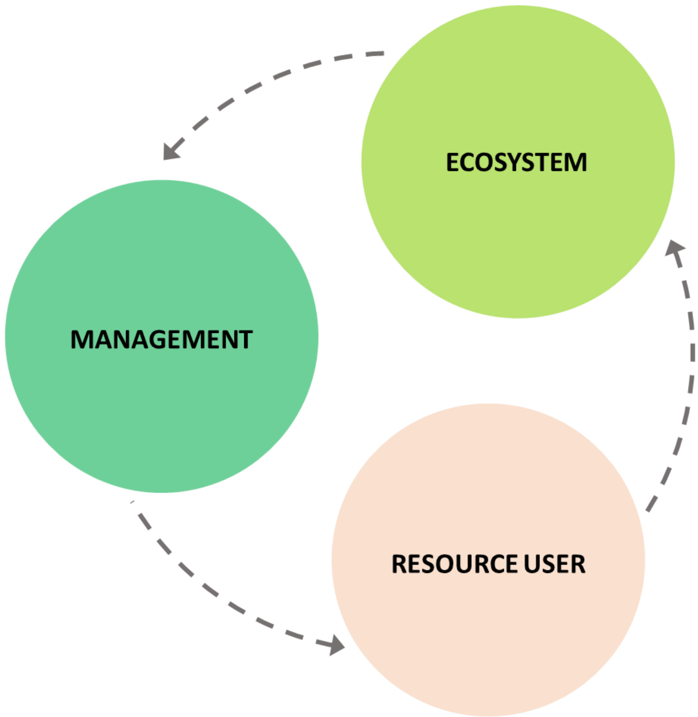

Figure 1.2. Traditional top-down conservation. Interrelations between the three dimension of conservation planning (ecosystem, resource users and management) are usually viewed in a given direction. Management measures are aligned with ecological settings and imposed on resource users.

In order to gain knowledge and understanding from various perspectives prevailing at Lake Alaotra and to detect trade-offs between the different dimensions in conservation planning we analyzed the ecological state of the wetland ecosystem to close knowledge gaps and to provide an adequate basis for present and future ecosystem-based conservation measures. We determined the efficiency of a small-scale protected area at Lake Alaotra (Park Bandro) in order to evaluate a recently implemented bottom-up management approach. Moreover, we focus on the fishery sector accounting for the largest lake resource user group to understand its continuous growth in the face of declining catches (Figure 1.3.).

The major aims of the study were:

i. to assess the ecological state of Lake Alaotra, based on water quality and vegetation parameters (**Chapter 3**).

ii. to evaluate the efficiency of Park Bandro regarding its small size and its community-led management as an example for local nature protection (**Chapter 4**).

iii. to investigate the drivers of overfishing, fishers' vulnerability and livelihood strategies (**Chapter 5**).

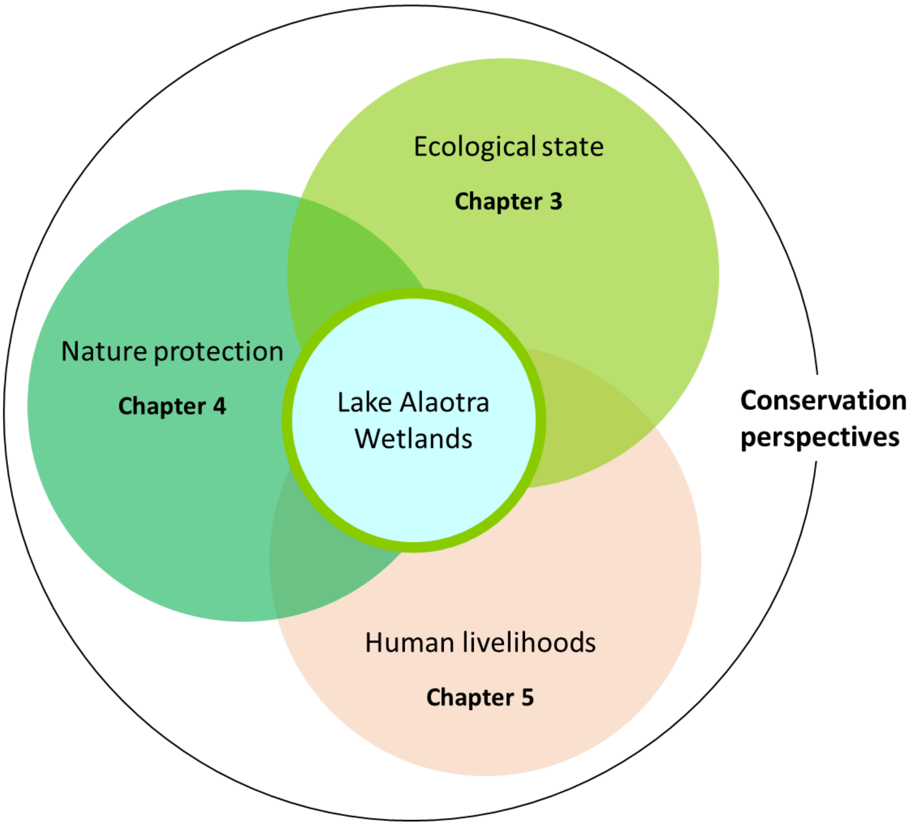

Figure 1.3. The three dimensions of conservation planning addressed in this thesis: the current state and future perspectives of the wetland ecology (**Chapter 3**), nature protection (**Chapter 4**) and resource use (**Chapter 5**).

Chapter 2

METHODS

2.1. Study area

Geography and climate: Lake Alaotra (E048° 26', S17° 31') is placed in a watershed encompassing 685,500 ha (Ferry et al. 2009) in the Alaotra-Mongoro region in northeastern Madagascar. The lake is located 750 m above sea level and is surrounded by hills, rising up to 1300 m (Bakoariniaina et al. 2006). The main tributaries of Lake Alaotra are the Sasomangana and the Sahabe, and the Anony and the Sahamaloto in the south and north, respectively. The Maningory River is the sole outlet of the lake (Chaperon et al. 1993, Mietton et al. 2018). The region is characterized by a tropical climate with two distinct seasons and a mean annual temperature of 20.6 °C. Nearly 90% of the annual rain (annual average of 900 to 1,250 mm) falls during the rainy season from November to March and rises the water level of the shallow lake (average water depths of 1.5 to 2 m) to a maximum of 4 m, flooding an area of 35.000 ha (Pidgeon 1996, Mutschler 2003, Ferry et al. 2009). Especially at the beginning of the rainy season precipitation patterns are extremely irregular and often linked to cyclons (Ducrot and Capillon 2004, Bruelle 2014).

Flora and fauna: The wetland's marsh vegetation provides shelter, food, breeding and spawning ground for various endemic and rare species and therefore holds an important key role in biodiversity conservation. They are dominated by papyrus (*Cyperus papyrus subsp. madagascariensis*) and reed (*Phragmites australis*). Today, invasive aquatic plant species such as the water hyacinth *Eichhornia crassipes*, and the water ferns *Salvinia* spp. and *Azolla* spp. have invaded the shallow areas of the lake (Andrianandrasana et al. 2005).

The native fish fauna has changed remarkably due to the introduction of exotic fish species since the beginning of the 20th century. Prior to that, Lake Alaotra was home for the locally endemic *Rheocles alaotrensis* (Bedotiidae), the endemics *Ratsirakia legendrei* (before *Eleotris legendrei*, Eleotridae) and *Paratilapia polleni* (Cichlidae), and two eel species, *Anguilla mossambica* and *Anguilla marmorata*. At that time fish catches were dominated by *P. polleni* (Moreau 1979/80). The introductions of exotic fish species intended to reduce the spread of malaria by mosquito control (*Gambusia holbrooki*, 1940) or to improve fisheries productivity and thereby provide food for local people (*Carassius auratus,* ~1900*; Cyprinus carpio*, 1926; *Tilapia rendalli* 1955; *Oreochromis macrochir*, 1958; *O. mossambicus* and *O. niloticus*, 1961; *Micropterus salmoides*, 1962; *Channa maculata*, ~1980). However, these introductions resulted in vast devastations of the local fish community. The eastern mosquitofish (*G. holbrooki*) preferred to pray rather on larval fish than mosquito and the carnivore blotched snakehead (*C. maculata*) caused most likely the disappearance of the endemic *P. polleni.* Only two species, *A. mossambica* and *R. alaotrensis*, are still left from the native fish community and the latter is now endangered by extinction. Today, *Tilapia* species (including various hybrids) represent the largest share in current catches (Moreau 1979/80, Reinthal and Stiassny 1991, Mutschler 2003, Canonico et al. 2005, Wallace 2012, Máiz-Tomé et al. 2018).

The wetland's avifauna, including many rare bird species, has also experienced large changes. In the late 80s and early 90s, about 72 bird species were recorded at Lake Alaotra (cf. Pidgeon 1996), including the endangered Meller's Duck (*Anas melleri*), one of the four resident endemic wildfowl taxa of Madagascar (Pidgeon 1996, Young et al. 2013, Kaufman 2012). Recent surveys recorded a substantially smaller number (cf. Kaufman 2012), which suggests that the diversity of bird species has declined in the last decades.

Some very rare mammals can further be found in the Alaotran wetland vegetation. The locally endemic and critically endangered Alaotran gentle lemur (*Hapalemur alaotrensis*) is the worldwide only permanent marsh-living primate (Rakotoarisoa at al. 2015). A small carnivore, Durrell's vontsira (*Salanoia durrelli*), has been described only in 2010 and is already listed among the world's 100 most endangered species (Durbin et al. 2010, Baillie and Butcher 2012). Further, the brown mouse lemur (*Microcebus* aff. *rufus*), listed as vulnerable and with a declining population trend, inhabits the marshes (Ratsimbazafy et al. 2013).

Social and cultural values: The major ethnic group living around Lake Alaotra are the *Sihanaka* which means 'people of the swamps' (Mietton et al. 2018). As their name implies the Lake Alaotra wetlands are deeply rooted in their history, culture and tradition. The plants of the marshes are used as raw material for construction of fences, furniture and traditional houses as well as for fishing gear and handicrafts. Certain species are traditionally used as medicinal plants and in traditional ceremonies. Sacred places within the marshes and taboos ('*fadys*') testify to the cultural importance of the wetlands (Ramanampamonjy et al. 2003, Rakotoarisoa 2018).

Nature conservation management: The Alaotra wetlands have been designated as a Ramsar site of international importance in September 2008, covering 722,500 ha. Five years later the wetlands were declared further as a new protected area (NAP) based on national law and became part of the Madagascar Protected Area System (SAPM). Adopting the principle of GELOSE (*Gestion Locale Sécurisée*) and GCF (*Gestion Contrualisée des Forêts*) that follow the idea of bottom-up approaches, natural resource management has been transferred to local communities around Lake Alaotra (Razanadrakoto and Rafaliarison 2005, Pollini et al. 2014). Current conservation measures for Lake Alaotra are based on the 2006 Lake Alaotra

Management Plan, which has the aim to conserve natural resources and ensure their sustainable exploitation, and to protect vulnerable animal species like the Alaotran gentle lemur (Wallace 2012). The poor compliance to regulations and enforcement of laws leads to NAP Lake Alaotra being widely seen as a ‘paper park’.

Environmental threats and regional changes: The given demographic, political, socio-economic and environmental settings at Lake Alaotra are strongly interrelated and have resulted in a multitude of pressures as shown in Figure 2.1. These pressures are threatening the wetland ecosystem itself but also affect human livelihoods and nature conservation at Lake Alaotra. The main drivers for existing pressures are demographic growth, political instability and poverty. These are accompanied by insecure land rights, species introductions, poor infrastructure and education as well as irregular precipitation patterns unfavorable for farming.

These conditions resulted in overfishing, overgrazing, deforestation and agricultural intensification (Andrianandrasana et al. 2005, Bruelle 2014). The division of land between siblings is further leading to a gradual downsizing of agricultural parcels (Copsey et al. 2009b). Weak property rights push land owners to enter into sharecropping contracts and to the risk of welfare loss (see Bellemare 2009). Wastewater and agricultural pollutants alter the lakes water quality and foster the spread of invasive aquatic plants such as the water hyacinth (*Eichhornia crassipes*) and water ferns (*Salvinia* spp. and *Azolla* spp.). As these floating invasive plants are covering open water areas and congesting waterways, people in turn started to destroy the marshes to create open areas for fishing and new channels. Poverty, the lack of arable land and unpredictable harvests due to irregular rain patterns triggers the use of illegal fishing methods and materials, conversion of marshes into rice fields and the overhunting of waterfowl for food. Meanwhile political instability enhances corruption and marsh burning as a sign of political disaffection (Copsey et al. 2009a, Andrianandrasana et al. 2005, Wallace 2012, Bruelle 2014). As a consequence of this development the marsh vegetation is continuously destroyed and fragmented leading to habitat loss. Small fishes diminished due to the use of illegal fishing methods and small mesh sizes. The overall fish stock and waterfowl population is declining and rare species are threatened to extinction (e.g. *H. alaotrensis*). Land use intensification has resulted in soil fertility decline. Sedimentation from eroded deforested hills are leading to rice field and lake siltation. The political and poor economic situation are reflected by weak governance and mismanagement. Local people’s livelihoods are directly impacted by the resulting overall decline in agricultural harvest and fish catch.

Drivers	Pressures	State	Impacts	
Demographic growth Agricultural land saturation Pollution Poor education Poverty Lacking livelihood opportunities Poor infrastructure Unsecure land rights Political instability Intra- and interannual changes in precipitation Invasive species	Small mesh size use Illegal fishing method use Overfishing Marsh destruction for open fishing areas Marsh conversion into rice fields Marsh burning Overgrazing Waterfowl overhunting Water quality alteration Deforestation for charcoal Land share (siblings) Sharecropping contracts Intensification of agriculture Corruption Invasive species spread	Depletion of small fishes Fish stock decline Waterway clogging Marsh destruction & fragmentation Rare species population decline Habitat loss Soil fertility decline Lake siltation Rice field siltation Waterfowl population decline Soil erosion Poor governance Mismanagement	**Livelihoods**	Decline in agricultural harvest Fish catch decline High risk vulnerability
			Ecosystem	Species displacement, impoverishment & extinction Plant & animal community changes Wetland loss and degradation Ecosystem functions alteration
			Nature conservation	Poor law enforcement Mistrust in institutions Low compliance with rules

Figure 2.1. The indirect drivers, direct drivers (pressure), the observable changes (state) and the resulting impacts on livelihoods, the ecosystem and nature conservation.

Falling incomes and lacking livelihood opportunities are the origin of local populations poor adaptive capacities to changes and their high risk vulnerability. The wetland ecosystem is facing plant and animal community changes coming along with species displacement, impoverishment and extinction. The overall wetland loss and degradation is leading the alteration of ecosystem functions. A general mistrust in institutions, low compliance with rules and poor law enforcement makes the conservation of the Alaotra wetlands to an arduous task.

2.2. Summary of used methods

To assess the ecological state of the wetland system (**Chapter 3**) three sites were selected for data collection that differ in terms of geographical location, human population density and level of environmental degradation: Andreba, Anororo and Vohimarina. (see Section 3.2. in **Chapter 3** for detailed information about the three sites). Environmental parameters were collected from November 2012 to April 2013. The ecological status quo was assessed based on the water quality and vegetation parameters. Measurements included conductivity (µS cm^{-1}), pH, temperature (°C), dissolved oxygen concentration and saturation (mg L^{-1} and %, respectively), luminosity (lux), water depth (cm), phytodiversity, vegetation structure, plant species cover and composition as well as nutrient concentrations measurements of nitrite (NO_2^-), nitrate (NO_3^-) and phosphate (PO_4^{3-}). These data were collected in 1 m² plots aligned along nine transects established in the marsh vegetation and on the open water body (90 plots per site). The total number of measurements (water quality, n = 240 measurements in the dry season versus n = 672 measurements in the rainy season; nutrients, n = 60 measurements; vegetation parameters, n = 270 measurements) differs between water, vegetation and nutrient parameters and between season (see Section 3.2. in **Chapter 3** for detailed information about data collection).

In order to evaluate the efficiency of Park Bandro (**Chapter 4**) regarding its small size and its community-led management we conducted vegetation surveys (May to June 2014) to assess the habitat quality of Park Bandro for the Alaotran gentle lemur and we carried out structured interviews (December 2015) to appraise the park's socio-economic influence on the local community and their attitude towards Park Bandro. For vegetation surveys the floristic composition, vegetation physiognomy and plant coverage were assessed as determinants for the locomotion potential, food availability and retreat opportunities for the Alaotran gentle lemur. Vegetation parameters were sampled in the marsh belt, inside and outside Park Bandro to analyze whether the vegetation within the park boundaries maintains a better habitat quality than a comparable area outside Park Bandro. Interviews were conducted with two groups of local stakeholders specified beforehand. Group 1 (n = 49) includes local stakeholders who are involved in the management and direct conservation practices in Park Bandro (e.g. members of local conservation associations). Group 2 (n = 52) comprises local stakeholders who are not directly involved with park management but who might be affected by the park since they work within its perimeter (e.g. fishermen).

To investigate the drivers of overfishing and fishers' vulnerability and livelihood strategies (**Chapter 5**) we collected data about yearly fish production and number of fishermen. To draw a general picture of the Lake Alaotran fishery since its expansion in the middle of the 20th century, we surveyed fish catches to assess the current state of the fish stocks and performed interviews to gain understanding about fishers' livelihood, problems, behavior and attitudes. Fish surveys were conducted in 2013 and 2014 to measure fish catches regarding catch weight (g), number of caught fishes (n), fish species (or genus in case of tilapia and eel) and size of caught fishes (cm). A total of 859 catches were recorded at different times of the year (March to April 2013, January, June, September to October 2014) at four sites: Andreba, Anororo, Vohimarina and Andilana Sud. Locations encompass a range of community types, from little villages to bigger communes. Structured interviews were conducted in March 2017. Interviews were app. 30 minutes in duration and addressed issues about their work as a fisherman (e.g. gear specification, daily working routine, income and livelihood diversification) as well as their perception about changes, problems and the future of Lake Alaotra fisheries. 117 fishermen were interviewed, 28 to 30 in each of the four sites. Data about yearly fish production and number of fishermen were collected from literature and from the regional directorate of fish resources and fisheries (*Direction Régionale des Ressources Halieutiques et de la Pêche*) in 2017.

2.3 Ethical guidelines

The trust and support of the local population was a crucial prerequisite for the data collection. We therefore employed local people as research assistants and predominantly lived with local families of the different research regions. In any encounter with local residents, the objectives of the research were conveyed and current activities were explained to dispel suspicions and to inform about our work. Anonymity was guaranteed to all participants of interviews.

Chapter 3

Lake Alaotra wetlands: how long can Madagascar's most important rice and fish production region withstand the anthropogenic pressure?

Pina Lena Lammers, Torsten Richter, Patrick Olivier Waeber, Jasmin Mantilla-Contreras

Madagascar Conservation and Development (2015), 10 (S3): 116 –127

Abstract

The Alaotra wetlands represent the biggest lake and wetland complex in Madagascar and are home of several endemic species. The region constitutes the largest rice production area and inland fishery of Madagascar. Rice and fish are the main local sources of income. While the population has increased fivefold during the last 40 years, the growing need for resources is continuously increasing the pressure on the wetland system. In this study, vegetation and water parameters were collected within three sites differing by level of degradation in order to evaluate the current ecological state of the wetland. The results show that high levels of ongoing anthropogenic disturbance are favoring the formation of a new plant community in the fringe area of the marsh belt. This area is now dominated by invasive species such as the water hyacinth (*Eichhornia crassipes*) which shows a mean coverage up to 53% and water ferns (*Salvinia* spp.) with a mean coverage up to 31.4%. Lake water levels were very low and decreased during the dry season to a mean level of only 3 cm in the littoral zone. Signs of eutrophication like hypoxia (mean saturation of only 22%), increased phosphate concentrations (1.18 mg L^{-1}) and black colored, foul smelling water were observed. Under a likely scenario of growing anthropogenic pressures, it remains unclear what the current trends will bring for the wetland's future.

Résumé

La zone humide de l'Alaotra représente le plus grand lac et complexe de zones humides de Madagascar hébergeant plusieurs espèces endémiques. La région constitue la première production de riz et de pêche dulcicole de l'île. Le riz et les ressources piscicoles sont les principales sources de revenus locaux. L'effectif de la population humaine locale a été quintuplé au cours des dernières 40 années et les besoins en ressources ont augmenté en conséquence de sorte que les pressions sur la zone humide ont été exacerbées. Dans cette étude, des paramètres portant sur la végétation et l'eau du lac ont été collectés dans trois sites qui diffèrent par le niveau de dégradation pour évaluer l'état écologique actuel de la zone humide. Les résultats montrent que le niveau élevé des perturbations anthropiques favorise la formation d'une nouvelle communauté végétale sur la ceinture du marais. Cette zone est dominée par des espèces de plantes envahissantes à l'exemple de la jacinthe d'eau (*Eichhornia crassipes*) dont la couverture moyenne est de 53% et de la fougère d'eau (*Salvinia* spp.) avec une couverture moyenne de 31,4%. Les niveaux du lac sont bas et diminuent jusqu'à 3 cm de moyenne dans la zone littorale pendant la saison sèche. Des signes d'eutrophisation comme l'hypoxie (saturation moyenne de 22%), l'augmentation de la concentration de phosphate (1,18 mg L^{-1}) et la présence

d'eau de couleur noire et nauséabonde ont été observés. Dans un possible scénario avec une augmentation des pressions humaines, les tendances actuelles restent difficiles à comprendre pour l'avenir de la zone humide.

3.1. Introduction

Wetlands are diverse ecosystems, including both fresh water and marine habitats (sensu Van der Valk 2012). They build the transition zone between land and water and fulfill various ecological functions such as nutrient and groundwater retention and supply, flood control and flow regulation, sediment retention, erosion and salinity control, water purification and climate stabilization. Wetlands further provide crucial ecosystem services to humans such as water, fish, natural products (e.g., construction material, crafts and medicinal plants) and resources for agriculture, cattle farming and energy production, game, wood and services like facilitation of transport and recreation (Dugan 1990, Roggeri 1995, Mitsch and Gosselink 2000, Turner et al. 2000, Junk 2002).

The Alaotra wetlands, situated on the northeastern part of the Madagascar highlands, are formed by the Lake Alaotra (less than 20,000 hectares of open water body), and by 23,000 ha of fresh water marshes (Bakoariniaina et al. 2006, Copsey et al. 2009a). The surrounding 120,000 ha of rice fields constitute Madagascar's biggest rice production area with an annual yield of ca. 300,000 tons (Plan Régional de Développement 2005). In addition, Lake Alaotra supplies the country with 2,500 tons of freshwater fish annually (ibid). The wetland complex provides habitat for a variety of plant and animal species. At least three vertebrate taxa are microendemics: the Alaotra gentle lemur (*Hapalemur alaotrensis*) is Critically Endangered with an estimated population of less than 2,500 individuals in 2005 (Ralainasolo et al. 2006, Ratsimbazafy et al. 2013), the Madagascar rainbowfish *Rheocles alaotrensis* (Bedotiidae) (Reinthal and Stiassny 1991) and a recently described small carnivore *Salanoia durrelli* (Eupleridae) (Durbin et al. 2010).

Although declared as a Ramsar site of international importance in 2003 and '*Nouvelle Aire Protégée*' since 2007, the wetland system experiences continuous anthropogenic pressures and degradation (Peck 2004). During the last 50 years, the human population in the two lake districts has increased fivefold from some 110,000 inhabitants in 1960 (Pidgeon 1996) to over 560,000 inhabitants (INSTAT 2013) leading to a steadily increasing demand for natural resources and agricultural land. While the fresh water marshes are shrinking due to burning and conversion into rice fields, the lake suffers from massive overfishing. Further problems include the invasion of non-native fish and plant species. Among invasive plant species, the water hyacinth

(*Eichhornia crassipes*) is one of the most problematic while it causes several ecological, social and economic problems; water loss due to increased evapotranspiration, oxygen loss, decreased phytoplankton productivity (associated with changes in the food web) due to decreasing light conditions, loss of biodiversity and clogging of waterways (Masifwa et al. 2001, Rommens et al. 2003, Mangas–Ramirez and Elias–Gutierrez 2004, Andrianandrasana et al. 2005, Villamagna and Murphy 2010).

Water loss and the decreasing open water surface represent serious problems in the area since Lake Alaotra is a shallow lake with a maximum depth of four meters. Sedimentation, transformation of water and streams for agricultural irrigation and environmental degradation have already reduced the lake to 20–30% of its original size (Bakoariniaina et al. 2006, Kusky et al. 2010). Shallowness and tropicality imply that physical aspects of water depth and water temperature are the determining features in the environmental regulation of the lake system (Talling 2001). Shallow lakes show a higher sensitivity towards rapid changes in those two parameters. While wetlands in tropical Africa seem to be well documented (e.g., Lake Chilwa (two meters depth, Howard-Williams 1975), Lake Chad (four meters depth, El-Shabrawy and Al-Ghanim 2012), Lake George (2.4 m depth, Ganf 1974), Lake Naivasha (four meters depth, Gaudet 1977), Lake Nakuru (four meters depth, Vareschi 1982), there is a lack of research on freshwater lakes in Madagascar. For Lake Alaotra, studies have mainly focused on population biology, distribution and behavior of vertebrate species, especially on *Hapalemur alaotrensis*, as well as on bird and fish species (Wilmé 1994, Mutschler et al. 1998, Hawkins et al. 2000, Nievergelt et al. 2002, Waeber and Hemelrijk 2003, Ralainasolo 2004, Ralainasolo et al. 2006, René de Roland et al. 2009, Guillera-Arroita et al. 2010). There are few studies only including ecological data and interactions, e.g., studies focusing on different trophic levels and on the consequences of environmental changes on habitat quality and biodiversity. The last comprehensive study about the ecological state of the lake dates back to some 20 years (Pidgeon 1996). The marsh vegetation is important in terms of habitat and food source for terrestrial and aquatic communities. Changes in vegetation heterogeneity and composition are therefore important attributes to assess ecosystem functioning. Physico-chemical features of the water (e.g., water level and temperature, dissolved oxygen, pH, luminosity, conductivity and nutrient content) are determining ecological parameters for aquatic communities (Lévêque 1997, Prepas and Charette 2003, Ekau et al. 2010). However, the terrestrial system relies on the aquatic system as well. This article will present an update of the lake's water quality and vegetation parameters in order to draw some general conclusions on the current wetland conditions.

3.2. Material and methods

Study area: The study was conducted at Lake Alaotra (E048° 26’, S17° 31’), Madagascar (Figure 3.1.). The lake is situated 750 m above sea level and lies in a tectonic basin encompassing an area of 685,500 ha (Andrianandrasana et al. 2005, Ferry et al. 2009, Kusky et al. 2010). The lake is shallow with water depths of 1.5 to 2 m on average and a maximum of 4 m during the rainy season (Pidgeon 1996). The lake obtains water from infiltration, runoff and flooding (Ramsar 2007). Four main rivers feed the Lake Alaotra: the Anony and the Sahamaloto in the north and the Sasomangana and the Sahabe in the south. The Maningory in the northeast constitutes its effluent (Chaperon et al. 1993). The Alaotra region is characterized by a tropical climate. Mean annual temperature is 20.6 °C, but ranges from 11.1 °C in July to 28.4 °C in January (Ferry et al. 2009). The basin is characterized by an annual precipitation of 900 to 1,250 mm with a maximum of 250 mm in January during the warm rainy season (November–March).

The freshwater marshes of Lake Alaotra are dominated by sedges and grasses. The higher strata is presented by common reed (*Phragmites australis*), cyperus (*Cyperus madagascariensis*) and the Convolvulaceae, *Argyreia vahibora*, while the lower strata is settled by *Cyperus latifolius*, *Leersia hexandra*, the fern *Cyclosorus interruptus*, *Persicaria glabra* and *Echinochloa pyramidalis* (Mutschler and Feistner 1995, Pidgeon 1996, Ranarijaona 2007). At least three invasive species have colonized successfully the shallow areas of the lake: the invasive *Eichhornia crassipes*, and the water ferns *Salvinia molesta* and *Azolla* spp. (Andrianandrasana et al. 2005).

Study sites: Three different sites were chosen for this study in terms of location at the lake, human population density and level of degradation: Andreba, Anororo and Vohimarina (Figure 3.1.). The level of degradation was defined a priori by (i) protection status and existence of local management units for the marshes, (ii) abundance of the invasive *Eichhornia crassipes*, (iii) intensity of fishery activities, (iv) presence of sanitation and (v) water level. Evaluation of the criteria was based on information from the *fokontany* (smallest administrative unit in Madagascar) and direct observations. Vohimarina, on the northern side of Lake Alaotra (E048° 32' 59.7”, S17° 20' 02.4”, 761 m a.s.l.) has a population of less than 500 inhabitants and encompasses 300 ha of marshes (Andrianandrasana et al. 2005); its marshes are defined as low-degraded (D1). It is described by a low water level, a village with low fishery activities and a low *E. crassipes* occurrence as well as the presence of sanitation and a community-based association (VOI, *Vondron' Olona Ifototra*) for the management of the marshes. Andreba, on the east side of the lake (E048° 30' 08.0”, S17° 37' 51.7”, 739 m a.s.l.) has 4,800 inhabitants and 235 ha of marshes (Andrianandrasana et al. 2005). Its marshes are intermediate-degraded (D2). Like Vohimarina, Andreba has a sanitation and a VOI but differs in terms of increased fishery activities and higher abundance of *E. crassipes*. Anororo, on the west side of the lake (E048° 26' 01.4", S17° 30' 44.0", 724 m a.s.l.) has a population of 8,000 inhabitants (Copsey et al. 2009b) and entails 9,850 ha of marshes (ibid). Water levels are higher than in the other sites. Its marshes are considered as highly-degraded (D3) because of a high occurrence of *E. crassipes* combined with high fishery activities, no sanitation and the absence of the VOI in 2012/13.

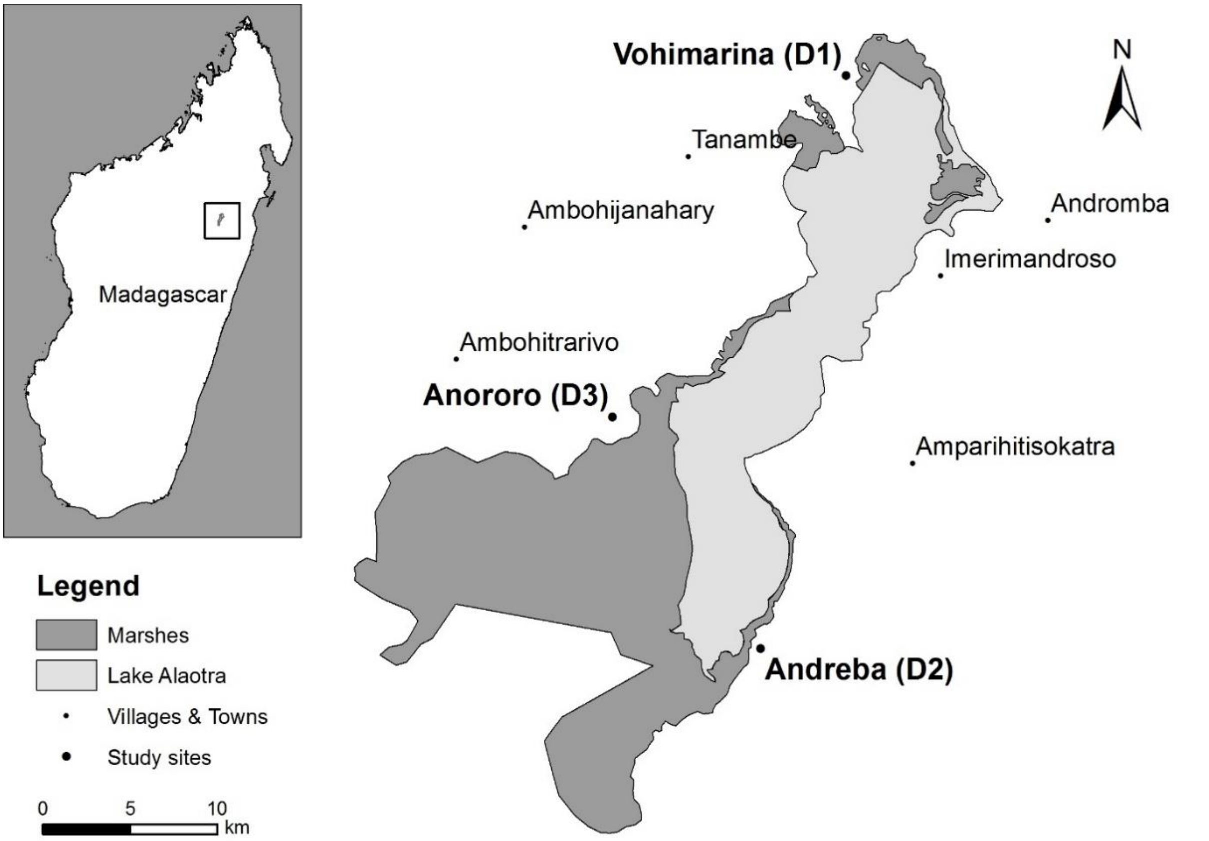

Figure 3.1. Location of the Alaotra wetlands and the study sites Vohimarina (D1), Andreba (D2) and Anororo (D3). (Modified from Durrell 2012)

Data sampling: Environmental parameters were assessed in the marsh vegetation and open water of the lake across all three sites from November 2012 to April 2013. For each study site, 9 line transects (each of 220 m length and 1 m width) were established along the lake shore (Figure 3.2. a, b). At all three locations, a canal represents the main connection between the village and the lake. Through the canal, municipal and agricultural wastewater is discharged directly into the lake. Further, the canal and its surroundings are subjected to mechanical disturbance by frequent boat traffic, fishery and cultivation activities. To detect habitat changes along a nutrient and mechanical disturbance gradient, four transects were placed on both sides of the canal and one transect was located near the canal (10 m). The ecological state of Lake

Alaotra was assessed by sampling vegetation and water parameters. Vegetation parameters were assessed in all transects, whereas the water parameters were determined in the core-transects only (Figure 3.2. a, b).

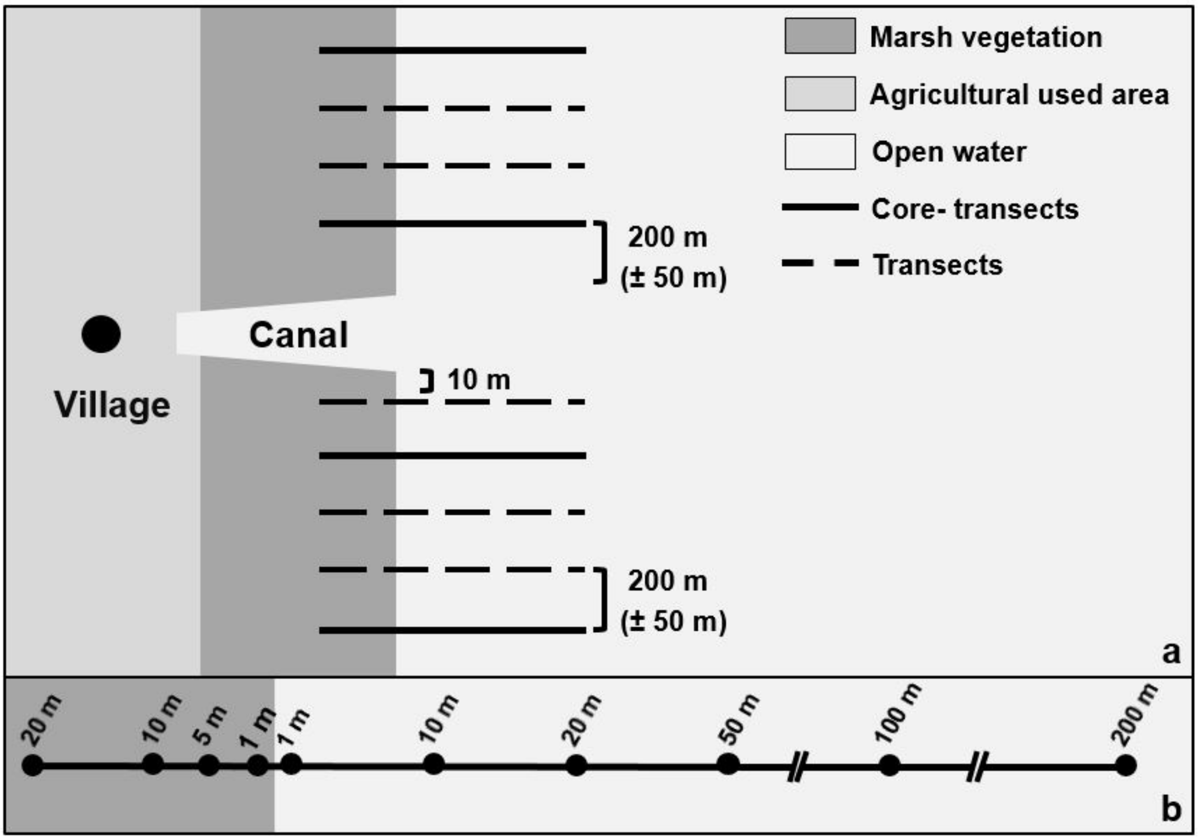

Figure 3.2. Direction and location of transects and plots in the littoral zone of Lake Alaotra. (a) Four transects were set out on each sides of the canal. One transect was additionally installed near the canal (1 0 m distance). (b) In each transect, a total of ten 1 m²-plots were installed, four in the lake shore vegetation – 20, 1 0, 5 and 1 m from the water edge – and six plots in the open water – 1, 10, 20, 50, 100 and 200 m from the lake shore vegetation. (The geographical coordinates of all plots were determined using a UTM, WGS 84 GPS).

Water parameters: The water depth (cm) was determined using a measuring rod. Water quality was assessed by measurements of conductivity (µS cm^{-1}), pH, temperature (°C) and dissolved oxygen (mg L^{-1} and %). All water quality measurements were performed with a digital multi-meter (WTW, Multi 350i). Luminosity (lux) was recorded with a digital lux-meter (PHYWE, model: 07137-00). Water quality and depth were sampled along the four core-transects. Daily physicochemical fluctuations were accounted by sampling the water parameters during four periods: 0700–1000h, 1000–1300h, 1300–1600h and 1600–1900h. The temporarily low water levels of the lake during the dry season made it difficult to reach the plots by boat and thus measurements were restricted to n = 20 per day. To detect seasonal changes, data were collected during the period of lowest lake water levels at the on set of the rainy season in 2012 (December 2012–January 2013; it only started raining in February; for brevity, it will be termed ‘dry season' for the remainder of this manuscript) and during March–April 2013; this will be termed 'rainy season'.

Sampling during the dry season was performed in surface water (0–10 cm depth) of the open water plots (10–200 m); due to higher water levels in the rainy season, analyzes were additionally done in plots within vegetation (20 and 10 m) and within deep water (1.5 m depth). In total n = 240 measurements were performed during the dry season versus n = 672 measurements in the rainy season.

Nutrient concentrations were measured during midday in two core-transects per site using a photometer (WTW, Photoflex Turb). Samples to detect nitrite (NO_2^-), nitrate (NO_3^-) and phosphate ($PO4_3^-$) were taken in the surface water (0–10 cm depth). For these measurements, open water plots (10 m to 200 m) during the dry season (December 2012–January 2013, n = 30) and the rainy season (March–April 2013, n = 30) were sampled. Ammonia (NH_4^+) could not be measured due to the high air temperatures at the study sites and the missing option for cooling.

Vegetation parameters: The lake shore vegetation was described using plant diversity, species abundance and composition as well as vegetation structure. Data were collected from February until March 2013 in all plots (n = 270). Plant species richness, total plant cover per plot and cover of each species were determined. Plant cover estimations were obtained in percentage for each plant species applying Londo's decimal scale (Londo 1976) and completed by open water and dead organic material cover estimates in percentage. Plant species were determined in the herbarium of the *Parc Botanique et Zoologique de Tsimbazaza*, Antananarivo, Madagascar. Vegetation structure was measured in all plots and was defined by vertical density of the vegetation, visually estimated as percentage in the plot (1 m section) for defined height intervals.

Data analyses: All statistical tests were done with the software SPSS for Windows (IBM, version 21). The comparison of data was performed with the nonparametric Mann-Whitney U-test for independent samples (two-tailed). Because of multiple comparisons α level ($\alpha = 0.05$) was lowered using the sequential Bonferroni correction (Bland and Altmann 1995, Abdi 2010). To detect site specific differences of plant species cover, plots without vegetation cover (100% open water surface) were excluded resulting in a sample size of n = 175. For the comparison of plant species abundance related to human disturbance, transects near the canal (200 m and 10 m) were compared with the ones located in a greater distance (400 m, 600 m, 800 m). Water parameters were analyzed with respect to seasonal changes, site specific differences, differences between deep and surface water, vegetation and open water. Water parameters within vegetation plots were analyzed separately because only sampled during the rainy season. Nitrite, nitrate and phosphate contents of the water were analyzed in order to detect seasonal changes and differences between the low-, the intermediate- and the high-degraded site.

3.3. Results

Conductivity: The concentration of dissolved material present in ionic form was generally low for all the study sites (Table 3.1.). During the dry season, mean values ranged from 79 $\mu S\ cm^{-1}$ in Vohimarina (D1) to 98 $\mu S\ cm^{-1}$ in Andreba (D2). In contrast, during the rainy season mean values decreased significantly ($p \leq 0.001$, $n = 160$) to a range between 50 $\mu S\ cm^{-1}$ for Anororo (D3) and 81 $\mu S\ cm^{-1}$ for Vohimarina (D1).

pH: During the dry season, mean values of pH measured in the surface water ranged between 6.8 in Andreba (D2) to 7.0 in Anororo (D3). In the rainy season, the pH ranged from around 6.4 (D2 and D3) to 7.4 (D1) (Table 3.1.). Minimum pH ranged between 5.6 and 6.1 in the dry season and 6.0 to 6.5 in the rainy season (Table 3.2.).

Water level: The water level of Lake Alaotra was subjected to high seasonal fluctuations (Table 3.1.). During the dry season, the water level in the littoral zone ranged from 14.6 cm (D3) to 11.7 cm (D1) and was extremely low in Andreba (D2) with a mean level of three centimeters (Figure 3.3. a, b). In the rainy season it raised up significantly ($p \leq 0.001$, $n = 160$) ranging between 182 cm in Andreba (D2) and 205 cm in Vohimarina (D1).

Temperature: Temperatures in the surface water were generally high in the dry season with mean values around 30 °C and an extreme value of 41.3 °C measured in Andreba (D2), the study site with lowest water levels (Table 3.1.). In the rainy season, the mean temperature of the surface water at site D1 and D3 was significantly lower ($p \leq 0.001$, $n = 160$) than in the dry season with 25.7 °C. No seasonal difference was determined at site D2 with a mean of 29.6 °C in the rainy season (Figure 3.3. c, d). A significant temperature decline (D1, D2: $p \leq 0.001$, $n = 160$; D3: $p = 0.006$, $n = 160$) regarding the water depth occurred within all three sites.

Oxygen: The highest concentrations of dissolved oxygen (DO) in the dry season were measured in Anororo (D3) with a mean of 92% (6.3 $mg\ L^{-1}$) implicating supersaturation of oxygen prevailing around midday in Anororo: 43% of the measurements exhibited DO concentrations higher than 100% (Figure 3.3. e, f). Lowest oxygen concentrations during the dry season were measured in Andreba (D2) with a mean of 52% (3.7 $mg\ L^{-1}$).

Table 3.1. Mean ($\overline{x}$), standard deviation (SD) and range (Min., Max.) of the water parameters at the three study sites with different level of degradation (Vohimarina, D1 = low, Andreba; D2 = intermediate, Anororo; D3 = high. Presented are data measured within the open water in the dry season (surface water) and the rainy season – surface water and deep water – determined during four periods a day: 7000–1000h, 1000–1300h, 1300–1600h and 1600–1900h. Asterisks shown with the values of the dry season (surface water) indicate statistically significant differences between dry and rainy season (n = 160). Asterisks presented with the values of the rainy season (deep water) indicate statistically significant differences between surface and deep water (n = 160); significance level: $p \leq 0.05$ = *, $p \leq 0.01$ = **, $p \leq 0.001$ = ***).

		Water parameters	D1 (n= 80)				D2 (n= 80)				D3 (n= 80)			
			$\overline{x}$	SD	Min.	Max.	$\overline{x}$	SD	Min.	Max.	$\overline{x}$	SD	Min.	Max.
Surface water (0–10 cm)	Dry season	Conductivity (µS cm^{-1})	80***	12,1	65	131	98***	20	67	156	89***	14,6	62	116
		DO (mg L^{-1})	5,0	1,6	0,1	7,4	3,7	1,9	0,1	7,7	6.3***	1,1	2,3	8,0
		DO (%)	70	21	1,2	99	52	28	1,6	135	92***	18,9	30	123
		pH	6.9***	0,2	5,6	7,3	6.8***	0,3	6,2	7,9	7.0***	0,3	6,1	7,6
		Temp (°C)	29.6***	3,0	21,9	36,4	30,8	4,4	21,3	41,3	29.8***	3,7	23,2	36,8
		Max. Water level (cm)	11.7***	4,6	0,5	23	3.0***	2,3	1,0	10,0	14.6***	4,4	7,0	22
		Light (lux)	919**	699	46	2839	326***	263	14,3	1272	1826***	1407	23	6350
	Rainy season	Conductivity (µS cm^{-1})	64	2,4	60	81	81	9,7	66	109	50	6,1	31	62
		DO (mg L^{-1})	5,3	0,7	3,9	6,6	3,4	2,1	0,2	7,5	3,1	1,5	0,5	8,0
		DO (%)	69	9,4	44	89	50	32	2,3	117	42	22	6,7	110
		pH	7,4	0,3	6,5	8,3	6,4	0,2	6,1	6,8	6,4	0,3	6,0	7,0
		Temp (°C)	25,7	0,9	24,0	29,1	29,6	2,7	26,0	35,3	25,7	1,3	23,5	29,4
		Max. Water level (cm)	205	6,9	195	220	182	9,2	170	205	195	4,9	185	200
		Light (lux)	530	419	10,0	1779	149	143	0,0	525	1066	1422	0,0	6830
Deep water (150 cm)	Rainy season	Conductivity (µS cm^{-1})	64	1,3	58	69	95***	11,3	74	122	50	5,3	41	59
		DO (mg L^{-1})	5,4	0,7	3,2	6,8	2.1*	0,4	1,2	3,1	3,1	0,9	1,7	5,0
		DO (%)	72	9,0	47	89	28**	5,0	16,6	43	41	12,2	22	65
		pH	7,4	0,4	6,5	8,3	6.3***	0,1	6,1	6,6	6,4	0,2	6,0	7,0
		Temp (°C)	25.1***	0,6	23,8	26,6	26.8***	0,7	25,8	28,2	25.0**	0,7	22,4	26,8
		Max. Water level (cm)	205	6,9	195	220	182	9,2	170	205	195	5,0	185	200
		Light (lux)	0.0***	0,0	0,0	0,0	3.8***	16,4	0,0	99	0.0***	0,0	0,0	0,0

Table 3.2. Mean ($\overline{x}$), standard deviation (SD) and range (Min., Max.) of nitrate, nitrite and phosphate at the three study sites with different level of degradation. (D1 = low, D2 = intermediate, D3 = high. Measurements in the dry season and in the rainy season are presented. Samples were taken during midday (1300h) in the surface water (depth = 0–10 cm). Asterisks shown with the values of the dry season indicate statistically significant differences between dry and rainy season; significance level: $p \leq 0.05$ = *, $p \leq 0.01$ = **, $p \leq 0.001$ = ***).

		Water parameters	D1 (n= 10)				D2 (n= 10)				D3 (n= 10)			
			$\overline{x}$	SD	Min.	Max.	$\overline{x}$	SD	Min.	Max.	$\overline{x}$	SD	Min.	Max.
Surface water	Dry season	Nitrite (mg L^{-1})	0.13***	0.02	0.11	0.16	0.04*	0.02	0.02	0.06	0.11***	0.06	0.04	0.17
		Nitrate (mg L^{-1})	4.36*	2.01	2.70	9.40	2.04***	0.77	1.30	3.60	2.88***	1.24	1.10	4.70
		Phosphate (mg L^{-1})	1.10	0.52	0.74	2.50	1.18	0.86	0.41	2.50	0.95**	0.23	0.61	1.36
	Rainy season	Nitrite (mg L^{-1})	0.06	0.01	0.05	0.09	0.07	0.04	0.03	0.15	0.06	0.03	0.03	0.13
		Nitrate (mg L^{-1})	5.31	0.44	4.70	6.20	5.32	0.77	4.50	6.70	4.96	0.32	4.30	5.30
		Phosphate (mg L^{-1})	0.97	0.67	0.22	1.07	0.63	0.30	0.29	1.06	0.45	0.25	0.33	2.50

Results of the rainy season showed a moderate decrease of DO at D1 and D2 compared to the dry season, while marked seasonal changes occurred in the highly-degraded site D3. Here the DO concentration dropped significantly ($p \leq 0.001$, n = 160) from 92% (6.3 mg L^{-1}) in the dry season to 41% (3.1 mg L^{-1}) in the rainy season (Figure 3.3. e, f). The degraded sites D2 and D3 were characterized by exceeding low oxygen concentrations within the mornings in the rainy season. The low-degraded site D2 showed a mean of only 22% (1.4 mg L^{-1}), the highly-degraded site D3 a mean of 26% (2.0 mg L^{-1}). Significant differences of oxygen concentrations between the marsh vegetation and the open water were only detected for the low-degraded site D1. Here, DO of the deep water within the vegetation (57%, 4.3 mg L^{-1}) was significantly lower ($p \leq 0.001$, n = 112) than in the open water (72%, 5.4 mg L^{-1}).

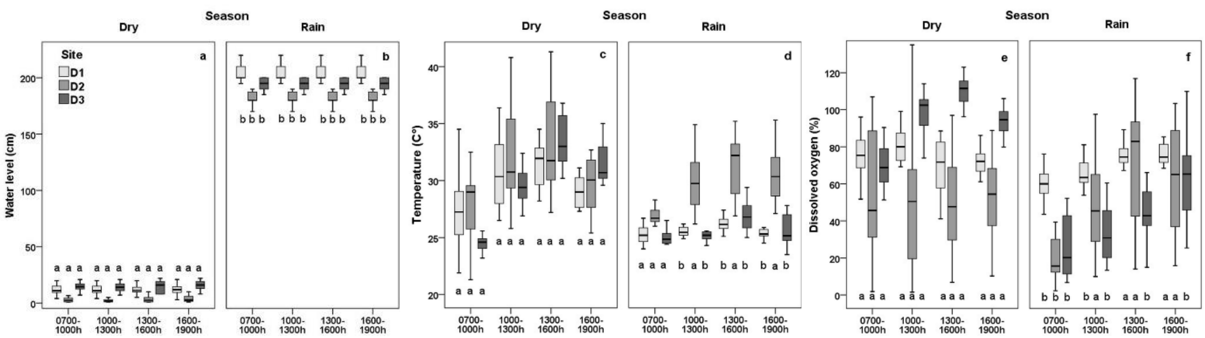

Figure 3.3. Box–whisker plots (showing median, upper and lower quartiles, and minimum and maximum values) of the daily range of water level (a, b), temperature (c, d) and dissolved oxygen (e, f) at the Lake Alaotra during the dry (left) and the rainy season (right) within the open water of the three study sites shown. (D1 = Vohimarina, D2 = Andreba, D3 = Anororo. Letters indicate statistically significant differences between dry and rainy season (n = 1 60) analyzed with Mann-Whitney U-Test and corrected by sequential Bonferroni method; significance was determined as $p \leq 0.05$).

Luminosity: The highest luminosity within the surface water in the dry season was measured at D3 with a mean of 1,826 lux (Table 3.1.). The lowest mean value was measured at D2 with 326 lux. A brown coloration of the water during the dry season (lower water levels) was observed more frequently, which was likely related to sediments stirred up by fishes. During the rainy season, a significant decrease of luminosity was observed for all sites with lowest light penetration of 1 49 lux within the water column in D2 ($p \leq 0.001$, $n = 160$) and highest luminosity of 1066 lux in D3 ($p \leq 0.001$, $n = 160$). Low light penetration in the rainy season was often accompanied by a black colored, foul smelling water.

Nutrients: The average nitrate content ranged between 2.04 mg L^{-1} at D2 and 4.36 mg L^{-1} at D1 during the dry season (Table 3.2.). Nitrate rose up to mean values around 5.31 mg L^{-1} and was very similar in all three sites during the rainy season (Table 3.2.). Phosphate concentrations showed no site specific differences. PO_4^{3-} ranged between 0.95 mg L^{-1} at D3 and 1.18 mg L^{-1} at D2 during the dry season. PO_4^{3-} ranged from 0.45 mg L^{-1} at D3 to 0.97 mg L^{-1} at D1 during the rainy season (Table 3.2.). Nitrite concentrations differed significantly ($p \leq 0.001$, $n = 20$) between the sites in the dry season with values between 0.04 mg L^{-1} (D2) to 0.1 3 mg L^{-1} (D1).

Plant diversity and abundance: A total of 22 plant species were identified within the lake shore vegetation at all three sites. Most of the species are either native or naturalized (reproduce by themselves) (Appendix 5.). *Echinochloa pyramidalis* (mean cover = 11.5%), *Phragmites australis* (mean cover = 2.9%), the Polygonaceae *Persicaria glabra* (mean cover = 2.1%) and the Onagraceae *Ludwigia stolonifera* (mean cover = 6.2%) were the most abundant species within this group. Two endemic species were identified: *Argyreia vahibora* (mean cover = 2.2%) and *Cyperus madagascariensis* (mean cover = 0.7%). Two invasive species were the most abundant plant species: *Eichhornia crassipes* appeared with a mean cover of 25% followed by *Salvinia* spp. with 15.6%. While the number of species within the genus *Salvinia* is not yet clarified, it is assumed that at least one invasive species, *Salvinia molesta*, can be found at the lake.

Site specific plant composition: *Eichhornia crassipes* and *Salvinia* spp. were the most abundant plant species within the marsh vegetation bordering the open water. However, there was a high variation in species occurrence and cover between the three sites (Figure 3.4.). The abundance of *E. crassipes* increased with level of degradation: it dominated 53% of the lake shore vegetation at D3 followed by D2 where it had a cover of 24%. At D1, *E. crassipes* was nearly absent with a mean cover of 0.4% and a maximum of 10% cover which differed significantly to the other sites (D1 /D2: $p \leq 0.001$, $n = 120$).

Salvinia spp. characterized the intermediate-degraded site D2 with a significant higher mean cover compared to D1 and D3 (D1/D2: $p \leq 0.001$, n = 120; D2/D3: p = 0.001, n = 114). In D1, the native grass *Echinochloa pyramidalis* was the most abundant plant species with a significant higher cover than in D2 (p = 0.010, n = 120) and D3 (p = 0.014, n = 116). Hydrophytes occurred mainly in the most intact site D1: the water lily *Nymphaea nouchali* covered 8.6% of the open water. Its abundance was significantly lower in the intermediate-degraded site D2 (p = 0.017, n = 120) where *N. nouchali* was rare and in the highly-degraded site D3 (p = 0.009, n = 116) where it was absent. The Menyanthaceae *Nymphoides indica* appeared only in D1.

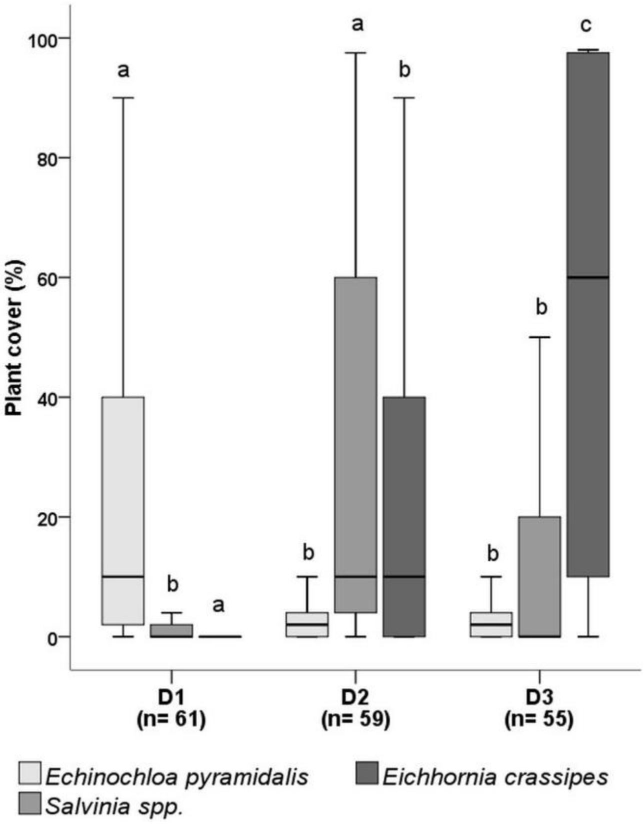

Figure 3.4. Box–whisker plots (median, upper and lower quartiles and minimum and maximum values) of the three most abundant plant species within the lake shore vegetation of Lake Alaotra. (D1 = Vohimarina, low-degraded; D2 = Andreba, intermediate-degraded; D3 = Anororo, highly-degraded. Differences between sites were analyzed with the Mann-Whitney U-Test using Bonferroni correction. Different letters above columns indicate significant differences; significance was determined at $p \leq 0.05$).

Total cover: In Vohimarina (D1) and Andreba (D2) the mean vegetation cover within the marsh belt accounted for 72% (SD = 33%, n = 36) and 74% (SD = 34% n = 36). The rest was represented by open water surface (D1: mean = 26%, SD = 32%, n = 36; D2: mean = 23%, SD = 31%, n = 36). In Anororo (D3), the vegetation accounted for only 45% (SD = 27%, n = 36) while the open water surface covered 53% (SD = 29%, n = 36).

Species abundance in relation to human disturbance: At the low-degraded site D1 the species abundance in transects near to the canal (CN) and transects far from the canal (CF) showed no statistically significant difference. At D2 the Onagraceae *Ludwigia stolonifera* had a significantly higher abundance in CN (CN: mean cover = 14.6%, SD = 19.1%; CF: mean cover

= 5.3%, SD = 10.8%; p = 0.012, n = 59). Although, *Eichhornia crassipes* exhibited also a higher abundance in CN at D2 the differences were not significant to CF. At D3, *E. crassipes* and *L. stolonifera* had a significantly higher cover in CN whereas *Salvinia* spp. was significantly less abundant. *E. crassipes* had a mean cover of 85.4% (SD = 28.3%) in CN and a significantly lower ($p \leq 0.001$, n = 55) cover of 34.4% (SD = 35.3%) in CF. *L. stolonifera* occurred with a significantly higher (p = 0.004, n = 55) mean cover of 12.9% (SD = 13.4%) in CN compared to CF (mean cover = 3.5%, SD = 7.73%). In contrast, *Salvinia* spp. were significantly less abundant (p = 0.036, n = 55) in CN (mean cover = 18.8%, SD = 4.6%) than in CF (mean cover = 29.0%, SD = 15.6%).

Vegetation structure: Vegetation structure varied between the three study sites and vegetation density increased with level of degradation. At D3 mean density was 76.5% at the ground level (0–3 cm) whereas it was only 25.9% at D1 (Appendix 6.). However, regarding the vertical vegetation density profile (Figure 3.5. a, b) the sites differed especially in the open water. Within the lake shore vegetation (Appendix 7.) density declined from 78.3% (0–3 cm) to 39.6% (50–100 cm) at site D3, 53.5% (0–3 cm) to 19.4% (50–100 cm) at D2 and from 33.2% (0–3 cm) to 17% (50–100 cm) at D1.

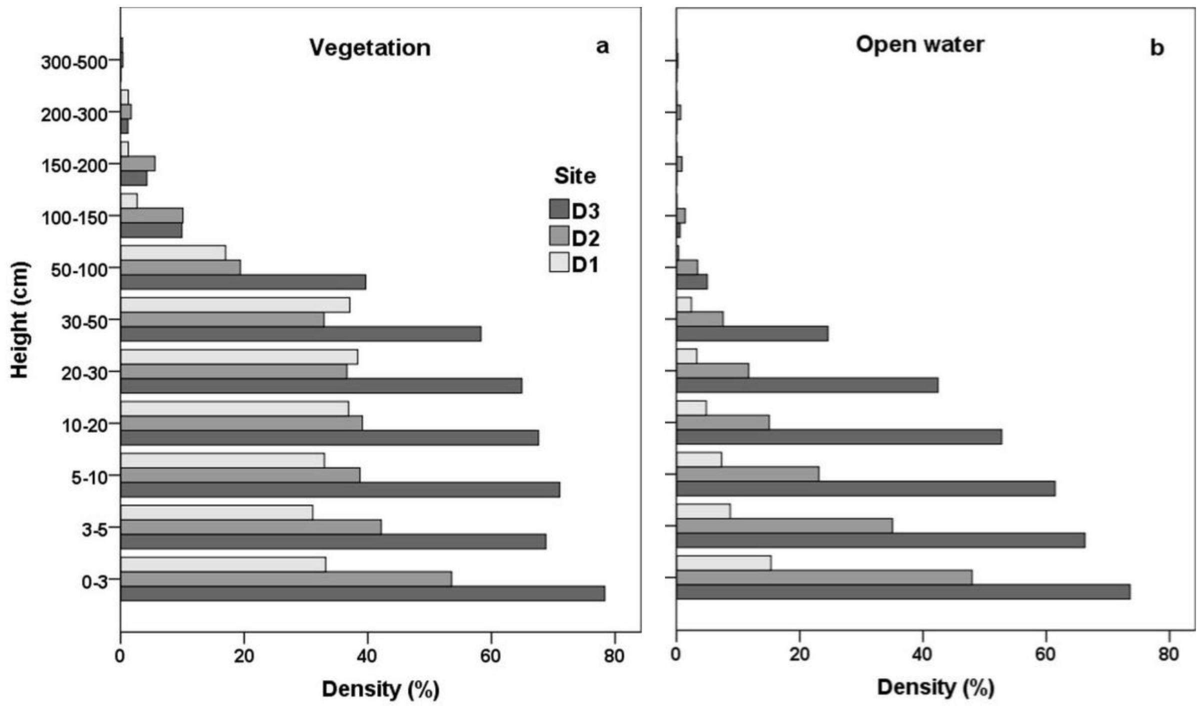

Figure 3.5. Vertical vegetation density (mean density in %) of the plots presenting the lake shore vegetation (a) and the open water (b) of the three study sites. (D = degradation level; 1 = low, 2 = intermediate, 3 = high).

In the open water (Appendix 8.) vegetation density ranged between 73.6% (0–3 cm) and 5.0% (50–100 cm) at site D3, 48.8% (0–3 cm) to 3.4% (50–100 cm) at D2 and 15.3% (0–3 cm) to

0.3% (50–1 00 cm) at D1. Regarding the vegetation height, at D1 and D2 vegetation reached a maximum height of 300–500 cm while the maximum height measured at D3 was only 200–300 cm (Appendix 6.). Accordingly, D3 was characterized by lower but denser vegetation whereas the intermediate- and low-degraded sites showed higher and more open vegetation.

3.4. Discussion

Classification of Lake Alaotra: Talling and Talling (1965) classified the African lakes based on their conductivity. Lake Alaotra with its low conductivity (50–98 μS cm^{-1}) belongs to Class I, characterizing lakes depending largely on rain and run-off or rivers of low salt content (Talling and Talling 1965, Payne 1986, Talling 2009) (e.g., Lake Victoria, Lung'ayia et al. 2001; Lake Tana, Kebede et al. 2006; and Lake Malawi, Chale 2011). Low conductivity is common for lakes fringed by marshes (Howard-Williams and Lenton 1975) like Lake Alaotra, as the vegetation absorbs and accumulate ions when inflow is passing through. consequently, the overall low conductivity leads to a low buffer capacity (alkalinity) of Lake Alaotra (cf. Talling and Talling 1965). Although highly vulnerable to acidification, Lake Alaotra still has a neutral pH (6.8–7.0) with partly slight acidic values around 6.0. Pidgeon (1996) described an acidic character of the open lake water (4.3–7.4). Current results are more similar to measured pH values (6.8–7.3) in the 1970s (Moreau 1980). Studies by Arhonditsis et al. (2003) and Araoye (2009) confirmed the spatial and temporal heterogeneity of pH in a lake system, which are derived mainly from photosynthetic and respiratory processes as well as nutrient loads (decomposition of organic matter and pollution). Measurements over a restricted time or of a small sample size are therefore highly influenced by daily, seasonal and regional patterns.

Water level: Recent studies show that Lake Alaotra has lost ca. 5 km² of open water surface over the past 30 years (Bakoariniaina et al. 2006). The cumulative effect of multiple factors can further aggravate this situation and eventually lead to the disappearance of the lake, these include: (i) erosion of surrounding hills leading to sedimentation and siltation downhill, (ii) higher evaporation due to vegetation clearance, and (iii) a lower water recharge into the lake due to rainwater percolation in fractures and faults and transformation of water and streams for agricultural irrigation (ibid). Besides a reduction in water surface, a diminution in its water depth as a main driver for the alteration of the abiotic conditions is crucial. Although no specific data is available for the evolution of the depth during the last century, the brownish red coloration of the rivers discharging into Lake Alaotra indicate the lake clearly as a sink for sediments (especially during the rainy season).

Water temperatures and oxygen level: The low water levels of Lake Alaotra imply high water temperatures due to quick heating of the water column. Average temperatures around 30 °C were reached in the surface water with a maximum of 41.3 °C measured in Andreba (D2). Other shallow lakes in the tropics show similar high temperatures in the upper water layers. The surface water of Lake George in Uganda for example reached temperatures of 36 °C (Ganf 1974).

The combination of low water levels and high temperatures can lead to a precarious decrease of dissolved oxygen in the water (Lévêque 1997). During the dry season, the low water column of the Lake Alaotra is heated up rapidly leading to very low solubility of dissolved oxygen (1.2%, 0.1 mg L^{-1}). A high oxygen demand from decaying organic material can deplete the level of oxygen as well (ibid). Typically for seasonal flooded wetlands such as the Alaotra wetlands, large amounts of organic matter and nutrients are carried into the lake when the first rains arrive (sensu Payne 1986). Additionally, the lower parts of standing vegetation are subjected to decomposition when water level rises. The considerable drop of the luminosity in the rainy season accounts for the deposition of suspended material in the lake. The marsh vegetation is normally acting like a buffer zone between the lake and surrounding agricultural areas because of its high nutrient uptake (Fisher and Acreman 2004). The high human population at sites D2 an D3 increases the pressure on the marshes. Large parts of the marshes have been converted into agricultural area minimizing their buffer capacity. This is aggravated by an increased nutrient load due to use of fertilizers and pesticides, decaying rice straws after rice harvest and direct wastewater discharges into the lake because of absence or lack of sanitation. Consequently, hypoxic conditions (1.4–2.0 mg L^{-1}) occurred at the more degraded sites during morning periods of the rainy seasons.

Possible response of aquatic communities to hypoxia: It is assumed that dissolved oxygen is becoming a determining factor for aquatic organisms in the Lake Alaotra. The shallow waters in the littoral zone represent habitat for aquatic invertebrate communities as well as foraging and nursery ground for fish species (Gilinsky 1984, Schramm and Jirka 1989, Petr 2000) and will be particularly affected. However, high water temperatures and low oxygen concentrations in the littoral of Lake Alaotra allow only zooplankton, macroinvertebrate and fish species with morphological, physiological and behavioral adaptations to resist such conditions (Marcus 2001, Ekau et al. 2010, Chang et al. 2013). Lake Alaotra's zooplankton is dominated by the water flea family Daphniidae (Pidgeon 1996). Several studies have proved a high hypoxia resistance of species belonging to the Daphniidae (Larsson and Lampert 2011, Smirnov 2013) while zooplankton abundance and distribution is generally negatively affected (Stalder and

Marcus 1997, Qureshi and Rabalais 2001, Roman et al. 2012, Chang et al. 2013). The aquatic macroinvertebrate taxa in Lake Alaotra are represented mainly by molluscs (Limnaea), mosquitoes (Culicidae), dragonflies (Coenagrionidae), mayflies (Baetidae), water-bugs (Heteroptera) and diving beetles (Dytiscidae) (Pidgeon 1996). Although, invertebrates exhibit a wide range of adaptations (Grieshaber et al. 1994, Verberk et al. 2008a, b) depleted oxygen levels can at least contribute to the near absence (Efitre et al. 2011). The fact that hypoxia tolerance is species- and stage-specific and varies widely (Miller et al. 2002) makes it difficult to predict changes in species composition, trophic pathways and productivity without further identification of the macroinvertebrate and zooplankton species of Lake Alaotra.

The ichthyofauna of Lake Alaotra is nowadays dominated by the hypoxia tolerant invasive *Tilapia* spp. and the snakehead fish *Channa maculata* (Moreau 1979/1980, Pidgeon 1996, Wallace et al. 2015). Snakeheads are able to uptake atmospheric oxygen (Yu and Woo 1985) while the aquatic breathing *Tilapia* spp. have hemoglobin with higher affinity to oxygen and can cope with hypoxia up to 2 mg L^{-1} (Dusart 1963, Philippart and Ruwet 1982, Verheyen et al. 1985). The native Anguillidae is less tolerant to hypoxia than *Tilapia* spp. (Hill 1969) and the tolerance range of oxygen concentration of the only left endemic fish species of Lake Alaotra, *Rheocles alaotrensis* (Batoidae) is not yet documented. In the near future those invasive species may outcompete completely the remaining native and endemic fish species due to their highly adapted metabolism to oxygen poor environments.

Intact marshes versus degraded marshes: Regarding oxygen levels, three site-specific differences can indicate the important role of marshes. (i) Vohimarina exhibited permanent normoxic levels whereas prolonged hypoxia occurred in the perturbed waters of Andreba and Anororo in the rainy season. A lower nutrient discharge into the lake and a higher nutrient uptake by the marsh belt is assumed at the low-degraded site. (ii) The open water of Vohimarina exhibited significant higher oxygen levels in comparison to the marsh belt. The water column of marshes is naturally characterized by lower oxygen concentrations than the open water based on its high primary production resulting in an increased oxygen demand from decomposition processes (Gaudet and Muthuri 1981, Howard-Williams and Thompson 1985, Lévêque 1997). In the degraded sites equalized oxygen conditions within the open water and the marshes might be the result of marsh clearance. (iii) At the highly-degraded site, a wide seasonal range of oxygen concentration has been observed. While hypoxic conditions were frequent in the rainy season, supersaturation arose in the dry season. An intact marsh belt seems to prevent near-shore areas from strong seasonal changes, since it can remove high amount of nutrients passing through at the beginning of the rainy season (Howard-Williams and Gaudet 1985). Related to nutrient discharge, supersaturated as well as hypoxic water could be a sign of eutrophication, which is nowadays widespread in tropical water bodies (Dudgeon et al. 2006).

Eutrophication: Eutrophication of lakes causes rapid growth of phytoplankton and aquatic plants with severe implications for water quality, food web, biotic community structure, biogeochemistry and littoral plant communities (Schindler 2006, Smith et al. 2006, Moss et al. 2011, Søndergaard et al. 2013). Due to the complexity of nutrient dynamics a high frequency of measurements over a long period is still necessary to enable drawing a representative statement about the trophic state of Lake Alaotra. Nevertheless, the current measurements allow to sketch first trends.

Although surrounded by large cultivated areas, the nitrate and nitrite values for Lake Alaotra are comparatively low. Both are far below the guideline values for drinking water with 50 mg L^{-1} for nitrate and 3 mg L^{-1} nitrite (WHO 2011). However, a comparison to nitrate measurements 20 years ago (Pidgeon 1996) manifests a doubling of the nitrate content in the Lake Alaotra.

Generally, low nitrogen contents are common for African lakes (Talling and Talling 1965). Nitrogen often occurs in its reduced form (ammonia) or bound in living plant stocks and sediments (Gaudet and Muthuri 1981, Payne 1986). The overall increase in nitrate during the rainy season can be explained by (i) nutrients (agricultural and natural origin) that were accumulated in the soil and washed out in the rainy season and (ii) large amounts of organic matter that reaches the lake with the first rain.

Elevated phosphate concentrations (1.18 mg L^{-1}), denote a beginning eutrophication. Samples taken in the 1970s (Moreau 1980) and in the 1990s (Pidgeon 1996) indicated lower concentrations. The origin of the phosphate might be from the release from anoxic sediments (internal loading) of Lake Alaotra and from external sources like pesticides, fertilizer and leaching from the weathered hills. Algae blooms (red or brown algae), observed in calm and shallow waters during the dry season at D2 could be directly related to the higher phosphate concentrations measured at Andreba (D2). Internal loading is accelerated by high water temperatures (Søndergaard et al. 2001) and therefore favorably occurs in quickly heated up shallow waters, during periods of high air temperatures and anoxic conditions. Enhanced phosphate concentrations, algae blooms, black colored and foul-smelling water and hypoxia are strong signs of eutrophication (Stahl 1979, Lamers et al. 1998, Lamers et al. 2002, Prepas and Charette 2003).

Plant community changes: In our study a total of 22 plant species were identified, considering the littoral zone of Lake Alaotra. Pidgeon (1996) found a similar number of 23 plant species when he sampled this zone. A comparison of the plant composition points out the changes in species dominance within the fringe area of the marsh belt. Twenty years ago, *Cyperus madagascariensis* and *Cyclosorus interruptus* were highly abundant within the lake shore vegetation, whereas nowadays they are continuously being reduced. *Cyperus madagascariensis* stands are used by local people for houses and mats (Mutschler 2003, Rendigs et al. 2015) and burned to extend the agricultural areas, pasture or open areas for fishing (Andrianandrasana et al. 2005). *Cyclosorus interruptus* was mainly observed inside of intact marsh vegetation of Lake Alaotra although it is known to occur in floating fringe areas of the marsh belt exposed to the sun (Hill et al. 1987, Geron et al. 2006). The growing anthropogenic impacts through cultivation, wastewater, biomass harvesting, fire, grazing and fishery is leading to the formation of new plant community types at Lake Alaotra. The most affected zone is the fringe area of the marsh belt due to its easy accessibility. Nowadays, fast growing species like *Ludwigia stolonifera*, *Echinochloa pyramidalis*, *Eichhornia crassipes* and *Salvinia* spp. characterize the vegetation fringing the water body. *Eichhornia crassipes* and *Salvinia* spp. also dominate the open water vegetation while the water lily *Nymphaea nouchali*, which covered once large parts of the lake before 1950 (Pidgeon 1996), seem to disappear and is only found where human activities are low.

The distribution pattern of the plant species at Lake Alaotra reflect the ongoing changes in species composition and show trends determining plant species abundance and composition in the future: (i) spread of invasive species: *Eichhornia crassipes* shows highest abundance where disturbance is most developed: in Anororo (D3) where intensive clearance has reduced lake shore vegetation to around 50% and in canal adjacency (D2 and D3), where nutrient load and mechanical disturbance tends to be highest. (ii) Raise of disturbance-tolerant native species: the native Ludwigia stolonifera, known as a plant with intense vegetative growth and rapid expansion (Sheppard et al. 2006, Lambert et al. 2010, Thouvenot et al. 2013), has become one of the prevailing species within the last twenty years (Pidgeon 1996) with a significant higher abundance in areas close to the canal. A study of Njambuya and Triest (2010) at Lake Naivasha (Kenya) has shown the ability of *L. stolonifera* to prosper in the presence of the *E. crassipes*. (iii) Plant species restriction to low disturbed sites: the wide spread of *Nymphaea nouchali* and *Echinochloa pyramidalis* exclusively at the low-degraded site (Vohimarina) denotes their sensitivity toward disturbance which is most likely physical damage by boat traffic and the dense mats of *Salvinia* spp. and *E. crassipes* which may restrict them from light and pressing them physically down.

Effects of the vegetation shift on aquatic and terrestrial communities: According to Huston (1979) only species capable of rapid recolonization and growth will persist to increased disturbance levels. Moreover, increased nutrient loads promote the dominance of a few highly competitive species and restrain other species (Pausas and Austin 2001). Changes in plant species composition and abundance during the last two decades and current spatial distribution pattern of plant species at Lake Alaotra highlight trends that will determine the plant community and abundance in the future. The spread of invasive and disturbance-tolerant native species as well as the disappearance of natural species communities occurring still at intact sites will be the main processes in vegetation changes affecting Lake Alaotra on an ecological and economic level (cf. Rakotoarisoa et al. 2015).

Eichhornia crassipes and *Salvinia molesta* have worldwide altered biodiversity, ecosystem functioning and services in wetlands (Mailu 2001, Calvert 2002, Charles and Dukes 2007). Many African lakes are nowadays invaded by invasive species (Ogutu-Ohwayo et al. 1997, Mailu 2001). Direct effects of the *E. crassipes* are modification of water clarity, monopolization of light, increased sedimentation, higher evapotranspiration rates, decrease of dissolved oxygen, nitrogen, phosphorous, heavy metals and other contaminants, changes in key habitat structure and waterway clogging (Toft et al. 2003, Jafari 2010, Villamagna and Murphy 2010, Katagira et al. 2011). Particularly the high evapotranspiration rates and sedimentation by the rotting mats (Sambasiva Rao 1988, Villamagna and Murphy 2010) pose a problem for Lake Alaotra due to its shallowness. Sediment deposits due to decomposition of dead plant material of floating *E. crassipes* mats will most likely play a minor role for the water depth and siltation of the lake as the sedimentation from the eroded hills has a strong impact on the lake.

The effects of *Eichhornia crassipes* on other aquatic communities are disparate: the abundance and diversity of epiphytic zooplankton and aquatic invertebrates are supported by the structural complexity of the *E. crassipes* roots and the increased habitat heterogeneity while the decreased food availability (phytoplankton) restricts their occurrence (Villamagna and Murphy 2010). At Lake Naivasha (Kenya) *E. crassipes* provides refuge for many invertebrates (Adams et al. 2002). Similarly, Pidgeon (1996) found higher species diversity in *E. crassipes* mats compared to aquatic grassland at Lake Alaotra. Thus, Pidgeon (1996) assumed that invertebrate abundance in the lake does not depend on diversity but density of aquatic plants.

Fish might benefit from a high abundance of epiphytic invertebrates, breeding grounds provided by *E. crassipes* and reduced predation risk (Mailu 2001, Villamagna and Murphy 2010) as it was the case in Lake Victoria in the 1990s (Mailu 2001, Njiru et al. 2002). However, the low phytoplankton biomass and oxygen concentration under the dense mats can affect negatively planktivorous fish and hypoxia sensitive species (Villamagna and Murphy 2010). Gichuki et al. (2012) documented the alteration of fish communities at Lake Victoria by *E. crassipes* promoting anoxia tolerant species. Hence, hypoxia-tolerant species of Lake Alaotra could benefit from the oxygen poor conditions under *E. crassipes* mats.

The terrestrial fauna might be affected by the higher density of *E. crassipes* modifying the habitat structure and heterogeneity. Harper et al. (2002) noted that foraging for the fish eagle is impeded by the *E. crassipes* mats covering Lake Naivasha (Kenya). Villamagna et al. (2012) suspected that changes in the seasonal waterbird community on Lake Chapala (Mexico) were related to *E. crassipes* cover. In Anororo the monospecific and dense *E. crassipes* mats have already caused wide changes in vegetation structure that can have a considerable bearing on the Lake Alaotra waterfowl and other terrestrial communities. Whether *E. crassipes* negative or positive influence prevails seems to depend on the size of the mats formed by *E. crassipes,* original communities and geographic distribution (Bailey and Litterick 1993, Villamagna and Murphy 2010, Chowdhary and Sharma 2013).

3.5. Conclusion

The results of this study demonstrate the continuously growing anthropogenic pressure on the Alaotra wetlands altering both water body and vegetation. Our major conclusions are that: (i) Low water levels in the dry season raising the water temperatures and favoring hypoxic conditions. (ii) A disturbed buffer function of the marshes results in depleted oxygen concentrations. (iii) A low buffer capacity makes the lake vulnerable to acidification. (iv) Signs of eutrophication such as foul smelling water, algae blooms and increased phosphate concentrations call for further long-term investigations of the trophic state of Lake Alaotra. (v) Anthropogenic activities on the lake and the surrounding marshes promote invasive plant species and disturbance tolerant species and repress native species. (vi) The encroachment of invasive species is highly correlated with human population density.

With a growing human population, resulting in increased demand for fish and agricultural products, the Alaotra wetlands will undergo further pressures. However, it is unclear how much more the lake can buffer in terms of water quality and vegetation alteration. If erosion, sedimentation, marsh clearance and nutrient load proceed unchecked, the cumulative effects may lead to an entire collapse of the Alaotra wetlands.

This article provides an insight in the current ecological state of Lake Alaotra. In consideration of the given facts about the demographic trends it is crucial to close gaps in knowledge about the ecological processes and functions of the lake to enable targeted management strategies and interventions. Further research should therefore (i) focus on the influence of the Alaotra marshes on the dissolved oxygen content in the water to estimate the minimum marsh belt width, which can guarantee its intact buffer function. For this purpose, the nutrient uptake and retention as well as the oxygen gradient from the fringe to the inner marshes has to be analyzed. (ii) To give a better understanding of nutrient sources and cycles, and the eutrophic state of Lake Alaotra, additional parameters like ammonia, total nitrogen and phosphorus as well as chlorophyll-a concentrations, lake turbidity using a Secchi disk and the biological oxygen demand are highly needed. Moreover, an investigation of the exchange processes between the sediment and the open water column and their role in nutrient cycling would clearly lead to a better understanding of the ongoing chemical processes within Lake Alaotra. (iii) As the Lake Alaotra plant community composition and structure undergo notable changes and the knowledge about the flora of the lake is incomplete and outdated, a plant inventory is needed to identify the occurring species and to know about their abundance. (iv) Further, studies regarding the disturbance tolerance of the plant species of Lake Alaotra can help to understand the alteration of the local plant community composition.

3.6. Acknowledgements

We would like to thank our field assistants Bernard Aimé Rajaonarivelo and Lala Nomenjanahary Elysé, the local community of Andreba, Vohimarina and Anororo for their hospitality, the University of Antananarivo, the Durrell Wildlife Conservation Trust Antananarivo and Ambatondrazaka and the Madagascar Wildlife Conservation for their collaboration and finally the "Stifterverband für die Deutsche Wissenschaft" for the financial support.

3.7. References

Abdi, H. 2010. Holm's sequential Bonferroni procedure. In: *Encyclopedia of research design*. N. J. Salkind (ed.), pp 1–8. Sage Publication, Thousand Oaks, California.

Adams, C. S., Boar, R. R., Hubble, D. S., Gikungu, M., Harper, D. M. et al. 2002. The dynamics and ecology of exotic tropical species in floating plant mats: Lake Naivasha, Kenya. *Developments in Hydrobiology* 168: 115–122.

Andrianandrasana, H. T., Randriamahefasoa, J., Durbin, J., Lewis, R. E. and Ratsimbazafy, J. H. 2005. Participatory ecological monitoring of the Alaotra wetlands in Madagascar. *Biodiversity Conservation* 14, 11: 2757–2774.

Araoye, P. A. 2009. The seasonal variation of pH and dissolved oxygen (DO_2) concentration in Asa lake Ilorin, Nigeria. *International Journal of Physical Sciences* 4, 5: 271–274.

Arhonditsis, G., Brett, M. T. and Frodge, J. 2003. Environmental control and limnological impacts of a large recurrent spring bloom in Lake Washington, USA. *Environmental Management* 31, 5: 603–618.

Bailey, R. G. and Litterick, M. R. 1993. The macroinvertebrate fauna of water hyacinth fringes in the Sudd swamps (River Nile, southern Sudan). *Hydrobiologia* 250, 2: 97–103.

Bakoariniaina, L. N., Kusky, T. and Raharimahefa, T. 2006. Disappearing Lake Alaotra: monitoring catastrophic erosion, waterway silting, and land degradation hazards in Madagascar using Landsat imagery. *Journal of African Earth Sciences* 44, 2: 241–252.

Bland, J. M. and Altman, D. G. 1995. Multiple significance tests: the Bonferroni method. *British Medical Journal* 310: 170.

Calvert, P. 2002. Water hyacinth control and possible uses. Technical brief. *International Technology Development Center*, UK. 11 pp.

Chale, F. M. 2011. Preliminary studies on the ecology of Mbasa (*Opsaridium microlepis* (Gunther)) in Lake Nyasa around the Ruhuhu River. *Journal of Ecology and the Natural Environment* 3, 2: 58–62.

Chang, K. H., Imai, H., Ayukawa, K., Sugahara, S., Nakano, S. I. and Seike, Y. 2013. Impact of improved bottom hypoxia on zooplankton community in shallow eutrophic lake. *Knowledge and Management of Aquatic Ecosystems* 408, 3: 1–8.

Chaperon, P., Danloux, J. and Ferry, L. 1993. *Fleuves et rivières de Madagascar*. Collection Monographie Hydrologique no.10, ORSTOM, Paris, France. 881 pp.

Charles, H. and Dukes, J. S. 2007. Impacts of invasive species on ecosystem services. In: *Biological invasions*. W. Nentwid (ed.), pp 217–237. Springer, Berlin.

Chowdhary, S. and Sharma, K. K. 2013. *Eichhornia crassipes* as a most preferred habitat for macrobenthic invertebrates. *Journal of Pharmaceutical and Scientific Innovation* 2, 4: 70–72.

Copsey, J. A., Jones, J. P., Andrianandrasana, H., Rajaonarison, L. H. and Fa, J. E. 2009a. Burning to fish: local explanations for wetland burning in Lac Alaotra, Madagascar. *Oryx* 43, 3: 403–406.

Copsey, J. A., Rajaonarison, L. H., Randriamihamina, R and Rakotoniaina, L. J. 2009b. Voices from the marsh: livelihood concerns of fishers and rice cultivators in the Alaotra wetland. *Madagascar Conservation and Development* 4, 1: 25–30.

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z. I., Knowler, D. J. et al. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Reviews* 81, 2: 163–182.

Dugan, P. J. 1990. *Wetland conservation: a review of current issues and required action*. IUCN, Gland, Switzerland. 96 pp.

Durbin, J., Funk, S. M., Hawkins, F., Hills, D. M., Jenkins, P. D. et al. 2010. Investigations into the status of a new taxon of *Salanoia* (Mammalia: Carnivora: Eupleridae) from the marshes of Lac Alaotra, Madagascar. *Systematics and Biodiversity* 8, 3: 341–355.

Dusart, J. 1963. Contribution à l'étude de l'adaptation des *Tilapia* (Pisces, Cichlidae) à la vie en milieu mal oxygéné. *Hydrobiologia* 21, 3–4: 328–341.

Efitre, J., Chapman, L. J., and Makanga, B. 2011. The inshore benthic macroinvertebrates of Lake Nabugabo, Uganda: seasonal and spatial patterns. *African Zoology* 36, 2: 205–216.

Ekau, W., Auel, H., Pörtner, H. O. and Gilbert, D. 2010. Impacts of hypoxia on the structure and processes in the pelagic community (zooplankton, macro-invertebrates and fish), *Biogeosciences* 7: 1669–1699.

El-Shabrawy, G. M. and Al-Ghanim, K. A. 2012. Aquatic habitats in Africa. Limnology of rivers and lakes. Encyclopedia of life supporting systems (EOLSS) UNESCO. 13 pp.

Ferry, L., Mietton, M., Robison, L. and Erismann, J. 2009. Alaotra Lake (Madagascar) – past, present and future. *Annals of Geomorphology* 53, 3: 299–318.

Fisher, J. and Acreman, M. C. 2004. Wetland nutrient removal: a review of the evidence. *Hydrology and Earth System Sciences* 8, 4: 673–685.

Ganf, G. G. 1974. Rates of oxygen uptake by the planktonic community of a shallow equatorial lake (Lake George, Uganda). *Oecologia* 15, 1: 17–32.

Gaudet, J. J. 1977. Natural drawdown on Lake Naivasha, Kenya, and the formation of papyrus swamps. *Aquatic Botany* 3: 1–47.

Gaudet, J. J. and Muthuri, F. M. 1981. Nutrient relationships in shallow water in an African lake, Lake Naivasha. *Oecologia* 49, 1: 109–118.

Geron, C., Owen, S., Guenther, A., Greenberg, J., Rasmussen, R. et al. 2006. Volatile organic compounds from vegetation in southern Yunnan Province, China: emission rates and some potential regional implications. *Atmospheric Environment* 40, 10: 1759–1773.

Gichuki, J., Omondi, R., Boera, P., Okorut, T., Matano, A. S. et al. 2012. Water hyacinth *Eichhornia crassipes* (Mart.) Solms-Laubach dynamics and succession in the Nyanza Gulf of Lake Victoria (East Africa): implications for water quality and biodiversity conservation. *The Scientific World Journal* 2012: #106429.

Gilinsky, E. 1984. The role of fish predation and spatial heterogeneity in determining benthic community structure. *Ecology* 65: 455–468.

Grieshaber, M. K., Hardewig, I., Kreutzer, U. and Pörtner, H. O. 1994. Physiological and metabolic responses to hypoxia in invertebrates. *Reviews of Physiology, Biochemistry and Pharmacology* 125: 43–147.

Guillera-Arroita, G., Lahoz-Monfort, J. J., Milner-Gulland, E. J. and Young, R. P. 2010. Monitoring and conservation of the critically endangered Alaotran gentle lemur *Hapalemur alaotrensis*. *Madagascar Conservation and Development* 5: 103–109.

Harper, D. M., Harper, M. M., Virani, M. A., Smart, A., Childress, R. B. et al. 2002. Population fluctuations and their causes in the African fish eagle (*Haliaeetus vocifer* (Daudin)) at Lake Naivasha, Kenya. *Hydrobiologia* 488: 171–180.

Hawkins, A. F. A., Andriamasimanana, R., Seing, S. T. and Rabeony, Z. 2000. The sad story of the Alaotra little grebe *Tachybaptus rufolavatus*. *Bulletin of the African Bird Club* 7, 2: 115–117.

Hill, L. G. 1969. Reactions of the American eel to dissolved oxygen tensions. *Texas Journal of Science* 20, 4: 305–313.

Hill, R., Webb, G. J. and Smith, A. M. 1987. Floating vegetation mats on a floodplain billabong in the Northern Territory of Australia. *Hydrobiologia* 150, 2: 153–164.

Howard-Williams, C. 1975. Vegetation changes in a shallow African lake: response of the vegetation to a recent dry period. *Hydrobiologia* 47, 3–4: 381–398.

Howard-Williams, C. and Gaudet, J. J. 1985. The structure and functioning of African swamps. In: *The ecology and management of African wetland vegetation*. P. Denny (ed.), pp 153–175. Springer, Netherlands.

Howard-Williams, C. and Lenton, G. 1975. The role of the littoral zone in the functioning of a shallow tropical lake ecosystem. *Freshwater Biology* 5, 5: 445–459.

Howard-Williams, C. and Thompson, K. 1985. The conservation and management of African wetlands. In: *The ecology and management of African wetland vegetation*. P. Denny (ed.), pp 203–230. Springer, Netherlands.

Huston, M. 1979. A general hypotheses of species diversity. *American Naturalist* 113, 1: 81–101.

INSTAT. 2013. Population et démographie de Madagascar. *Institut National de la Statistique*. Madagascar. http://www.instat.mg, January 26, 2014.

Jafari, N. 2010. Ecological and socio-economic utilization of water hyacinth (*Eichhornia crassipes* Mart Solms). *Journal of Applied Sciences and Environmental Management* 14, 2: 43–49.

Junk, W. J. 2002. Long-term environmental trends and the future of tropical wetlands. *Environmental Conservation* 29, 4: 414–435.

Katagira, F., Kyamanywa, S., Tenywa, J. S., Rajabu, C. A., Sombe, D. and Ndunguru, J. 2011. Impact of interspecific competition by compatriot aquatic weeds on water hyacinth *Eichhornia crassipes* (Martius) Solms growth and development in the Kagera River. *International Journal of Biodiversity and Conservation* 3, 8: 345–357.

Kebede, S., Travi, Y., Alemayehu, T. and Marc, V. 2006. Water balance of Lake Tana and its sensitivity to fluctuations in rainfall, Blue Nile basin, Ethiopia. *Journal of Hydrology* 316, 1–4: 233–247.

Kusky, T. M., Toraman, E., Raharimahefa, T. and Rasoazanamparany, C. 2010. Active tectonics of the Alaotra-Ankay graben system, Madagascar: possible extension of Somalian-African diffusive plate boundary? *Gondwana Research* 18, 2: 274-294.

Lambert, E., Dutartre, A., Coudreuse, J. and Haury, J. 2010. Relationships between the biomass production of invasive *Ludwigia* species and physical properties of habitats in France. *Hydrobiologia* 656, 1: 173–186.

Lamers, L. P. M., Tomassen, H. B. M. and Roelofs, J. G. M. 1998. Sulfate induced eutrophication and phytotoxicity in freshwater wetlands. *Environmental Science and Technology* 32, 2: 199–205.

Lamers, L. P. M., Falla, S. J., Samborska, E. M., Van Dulken, I. A. R., Van Hengstum, G. and Roelofs, J. G. M. 2002. Factors controlling the extent of eutrophication and toxicity in sulfate-polluted freshwater wetlands. *Limnology and Oceanography* 47, 2: 585–593.

Larsson, P. and Lampert, W. 2011. Experimental evidence of a low-oxygen refuge for large zooplankton. *Limnology and Oceanography* 56, 5: 1682–1688.

Lévêque, C. 1997. *Biodiversity dynamics and conservation: the freshwater fish of tropical Africa*. Cambridge University Press, Cambridge. 452 pp.

Londo, G. 1976. The decimal scale for releves of permanent quadrats. *Vegetatio* 33, 1: 61–64.

Lung'Ayia, H., Sitoki, L. and Kenyanya, M. 2001. The nutrient enrichment of Lake Victoria (Kenyan waters). *Hydrobiologia* 458, 1–3: 75–82.

Mailu, A. M. 2001. Preliminary assessment of the social, economic and environmental impacts of water hyacinth in the Lake Victoria basin and the status of control. In: Biological and integrated control of water hyacinth *Eichhornia crassipes*, pp 130–139. *ACIAR Proceedings N. 102*, Australia.

Mangas-Ramirez, E. and Elias-Gutierrez, M. 2004. Effect of mechanical removal of water hyacinth (*Eichhornia crassipes*) on the water quality and biological communities in a Mexican reservoir. *Journal of Aquatic Health and Management* 7, 1: 161–168.

Marcus, N. H. 2001. Zooplankton: responses to and consequences of hypoxia. In: *Coastal and estuarine studies: coastal hypoxia, consequences for living resources and ecosystems*. N. N. Rabalais and R. E. Turner (eds.), pp 49–60. American Geophysical Union, Washington, DC.

Masifwa, W. F., Twongo, T. and Denny, P. 2001. The impact of water hyacinth, *Eichhornia crassipes* (Mart) Solms on the abundance and diversity of aquatic macroinvertebrates along the shores of northern Lake Victoria, Uganda. *Hydrobiologia* 452, 1–3: 79–88.

Miller, D., Poucher, S. and Coiro, L. 2002. Determination of lethal dissolved oxygen levels for selected marine and estuarine fishes, crustaceans, and a bivalve. *Marine Biology* 140, 2: 287–296.

Mitsch, W. J. and Gosselink, J. G. 2000. The value of wetlands: importance of scale and landscape setting. *Ecological Economics* 35, 1: 25–33.

Moreau J. 1979/80. Le lac Alaotra à Madagascar: cinquante ans d'aménagement des pêches. *Cahier ORSTOM*. *Hydrobiologie* 3–4: 171–179.

Moreau, J. 1980. Essai d’application au lac Alaotra (Madagascar) d’un modèle d’étude de pêcheries pour les plaines d’inondation intertropicales. *Cahier ORSTOM. Hydrobiologie* 13, 1–2: 83–91.

Moss, B., Kosten, S., Meerhof, M., Battarbee, R., Jeppesen, E. et al. 2011. Allied attack: climate change and eutrophication. *Inland Waters* 1, 2: 101–105.

Mutschler, T. 2003. Lac Alaotra. In: *The natural history of Madagascar*. S. M. Goodman and J. P. Benstead (eds.), pp 1530–1534. The University of Chicago press, Chicago.

Mutschler, T. and Feistner, A. T. C. 1995. Conservation status and distribution of the Alaotran gentle lemur *Hapalemur griseus alaotrensis*. *Oryx* 29, 4: 267–274.

Mutschler, T., Feistner, A. T. C. and Nievergelt, C. M. 1998. Preliminary field data on group size, diet and activity in the Alaotran gentle lemur *Hapalemur griseus alaotrensis*. *Folia Primatologica* 69, 5: 325–330.

Njambuya, J. and Triest, L. 2010. Comparative performance of invasive alien *Eichhornia crassipes* and native *Ludwigia stolonifera* under non limiting nutrient conditions in Lake Naivasha, Kenya. *Hydrobiologia* 656: 221–231.

Nievergelt, C. M., Mutschler, T., Feistner, A. T. C. and Woodruff, D. S. 2002. Social system of the Alaotran gentle lemur (*Hapalemur griseus alaotrensis*). *American Journal of Primatology* 57, 4: 157–176.

Njiru M., Othina, A., Getabu, A., Tweddle, D. and Cowx, I. G. 2002. Is the infestation of water hyacinth, *Eichhornia crassipes* a blessing to Lake Victoria? In: *Management and ecology of the lake reservoirs fisheries*. I. G. Cowx (ed.), pp 255–63. Oxford Fishing News Books. Blackwell Science, Tokyo.

Ogutu-Ohwayo, R., Hecky, R. E., Cohen, A. S. and Kaufman, L. 1997. Human impacts on the African great lakes. *Environmental Biology of Fishes* 50, 2: 117–131.

Pausas, J. G. and Austin, M. P. 2001. Patterns of plant species richness in relation to different environments: An appraisal. *Journal of Vegetation Science* 12, 2: 153–166.

Payne, A. I. 1986. *The ecology of tropical lakes and rivers*. Wiley, Chichester, UK.

Peck, D. 2004. Madagascar designates its third Ramsar site. *Lemur News* 9: 3.

Petr, T. 2000. Interactions between fish and aquatic macrophytes in inland waters. A review. FAO Fisheries, Technical Paper 396, Rome. 185 pp.

Philippart, J. C. and Ruwet, J. C. 1982. Ecology and distribution of tilapias. In: *The Biology and Culture of Tilapias*. R. S. V. Pullin and R. H. Lowe-Mc Connell (eds.), pp 15–59. ICLARM Conference Proceedings 7, International Center for Living Aquatic Resources Management, Manila.

Pidgeon, M. 1996. An ecological survey of Lake Alaotra and selected wetlands of central and eastern Madagascar in analyzing the demise of Madagascar pochard *Aythya innotata*. *WWF/Missouri Botanical Garden*, Antananarivo, Madagascar. 139 pp.

Plan Régional de Développement. 2005. Région Alaotra-Mangoro, Province Autonome de Toamasina. Unpubl. Report.

Prepas, E. E. and Charette, T. 2003. Worldwide eutrophication of water bodies: causes, concerns, controls. In: *Treatise on Geochemistry*, 1st edition. H. D. Holland, K. K. Turekian, (eds.), pp 311–331. Elsevier, Oxford, UK.

Qureshi, N. A. and Rabalais, N. N. 2001. Distribution of zooplankton on a seasonally hypoxic continental shelf. In: *Coastal and estuarine studies: coastal hypoxia, consequences for living resources and ecosystems*. N. N. Rabalais and R. E. Turner (eds.), pp 61–76. American Geophysical Union, Washington, DC.

Rakotoarisoa, T. F., Waeber, P. O., Richter, T. and Mantilla-Contreras, J. 2015. Water hyacinth (*Eichhornia crassipes*), any opportunities for the Alaotra wetlands and livelihoods? *Madagascar Conservation and Development*. 10, S3: 128–136.

Ralainasolo, F. B. 2004. Action des effets anthropiques sur la dynamique de la population de *Hapalemur griseus alaotrensis* ou Bandro dans son habitat naturel. *Lemur News* 9: 32–35.

Ralainasolo, F. B., Waeber, P. O., Ratsimbazafy, J., Durbin, J. and Lewis, R. 2006. The Alaotra gentle lemur: population estimation and subsequent implications. *Madagascar Conservation and Development* 1, 1: 9–10.

Ramsar. 2007. Signatories and Sites. http://www.ramsar.org. January 15, 2014.

Ranarijaona, H. L. T. 2007. Concept de modèle écologique pour la zone humide Alaotra. *Madagascar Conservation and Development* 2, 1: 25–42.

Ratsimbazafy, J. H., Ralainasolo, F. B., Rendigs, A., Mantilla-Contreras, J., Andrianandrasana, H. et al. 2013. Gone in a puff of smoke? *Hapalemur alaotrensis* at great risk of extinction. *Lemur News* 17: 14–18.

Reinthal, P. N. and Stiassny, M. L. J. 1991. The freshwater fishes of Madagascar: a study of an endangered fauna with recommendations for a conservation strategy. *Conservation Biology* 5, 2: 231–243.

Rendigs, A., Reibelt, L. M., Ralainasolo, F. B., Ratsimbazafy, J. H.and Waeber, P. O. 2015. Ten years into the marshes – *Hapalemur alaotrensis* conservation, one step forward and two steps back*? Madagascar Conservation and Development* 10, S1: 13–20.

René de Roland, L. A., Thorstrom, R., Razafimanjato, G., Rakontondratsima, M. P. H. and Sam, T. S. 2009. Surveys, distribution and current status of the Madagascar harrier *Circus macrosceles* in Madagascar. *Bird Conservation International* 19, 4: 309–322.

Roggeri, H. 1995. *Tropical freshwater wetlands: a guide to current knowledge and sustainable management*. Kluwer Academic Publishers, Dordrecht, Netherlands. 349 pp.

Roman, M. R., Pierson, J. J., Kimmel, D. G., Boicourt, W. C. and Zhang, X. 2012. Impacts of hypoxia on zooplankton spatial distributions in the northern Gulf of Mexico. *Estuaries and Coasts* 35, 5: 1261–1269.

Rommens, W., Maes, J., Dekeza, N. and Ingelbrecht, P. 2003. The impact of water hyacinth (*Eichhornia crassipes*) in a eutrophic subtropical impoundment (Lake Chivero, Zimbabwe). I. Water Quality. *Fundamental and Applied Limnology* 158, 3: 373–388.

Sambasiva Rao, A. 1988. Evapotranspiration rates of *Eichhornia crassipes* (Mart.) Solms, *Salvinia molesta* ds Mitchell and *Nymphaea lotus* (L.) Willd. Linn. in a humid tropical climate. *Aquatic Botany* 30, 3: 215–222.

Schindler, D. W. 2006. Recent advances in the understanding and management of eutrophication. *Limnology and Oceanography* 51, 1: 356–363.

Schramm, H. L. and Jirka, K. J. 1989. Effects of aquatic macrophytes on benthic macroinvertebrates in two Florida lakes. *Journal of Freshwater Ecology* 5: 1–12.

Sheppard, A. W., Shaw, R. H., and Sforza, R. 2006. Top 20 environmental weeds for classical biological control in Europe: a review of opportunities, regulations and other barriers to adoption. *Weed Research* 46, 2: 93–117.

Smirnov, N. N. 2013. *Physiology of the Cladocera*. Academic Press. London, UK. 418 pp.

Smith, V. H., Joye, S. B. and Howarth, R. W. 2006. Eutrophication of freshwater and marine ecosystems. *Limnology and Oceanography* 51, 1: 351–355.

Søndergaard, M., Jensen, P. J. and Jeppesen, E. 2001. Retention and internal loading of phosphorus in shallow, eutrophic lakes. *The Scientific World Journal* 1: 427–442.

Søndergaard, M., Bjerring, R. and Jeppesen, E. 2013. Persistent internal phosphorus loading during summer in shallow eutrophic lakes. *Hydrobiologia* 710, 1: 95–107.

Stahl, J. B. 1979. Black water and two peculiar types of stratification in an organically loaded strip-mine lake. *Water Research* 13, 5: 467–471.

Stalder, L. C. and Marcus, N. H. 1997. Zooplankton responses to hypoxia: behavioral patterns and survival of three species of calanoid copepods. *Marine Biology* 127, 4: 599–607.

Talling, J. F. 2001. Environmental controls on the functioning of shallow tropical lakes. *Hydrobiologia* 458 1–3: 1–8.

Talling, J. F. 2009. Electrical conductance – a versatile guide in freshwater science. *Freshwater Reviews* 2, 1: 65–78.

Talling, J. F. and Talling, I. B. 1965. The chemical composition of African lake waters. *Internationale Revue der gesamten Hydrobiologie und Hydrographie* 50, 3: 421–463.

Thouvenot, L., Haury, J., and Thiebaut, G. 2013. A success story: water primroses, aquatic plant pests. *Aquatic Conservation: Marine and Freshwater Ecosystems* 23, 5: 790–803.

Toft, J. D., Simenstad, C. A., Cordell, J. R. and Grimaldo, L. F. 2003. The effects of introduced water hyacinth on habitat structure, invertebrate assemblages, and fish diets. *Estuaries* 26, 3: 746–758.

Turner, R. K., Van Den Bergh, J. C., Söderqvist, T., Barendregt, A., van der Straaten, J. et al. 2000. Ecological-economic analysis of wetlands: scientific integration for management and policy. *Ecological Economics* 35, 1: 7–23.

Van der Valk, A. G. 2012. *The biology of freshwater wetlands*. Oxford University Press, New York. 296 pp.

Vareschi, E. 1982. The ecology of Lake Nakuru (Kenya). III Abiotic factors and primary production. *Oecologia* 55, 1: 81–101.

Verberk, W. C. E. P., Siepel, H. and Esselink, H. 2008a. Life-history strategies in freshwater macroinvertebrates. *Freshwater Biology* 53, 9: 1722–1738.

Verberk, W. C., Siepel, H. and Esselink, H. 2008b. Applying life-history strategies for freshwater macroinvertebrates to lentic waters. *Freshwater Biology* 53, 9: 1739–1753.

Verheyen, E., Blust, R. and Doumen, C. 1985. The oxygen uptake of *Sarotherodon niloticus* L. and the oxygen binding properties of its blood and hemolysate (Pisces: Cichlidae). *Comparative Biochemistry and Physiology Part A: Physiology* 81, 2: 423–426.

Villamagna, A. M., and Murphy, B. R. 2010. Ecological and socio-economic impacts of invasive water hyacinth (*Eichhornia crassipes*): a review. *Freshwater Biology* 55, 2: 282–298.

Villamagna, A. M., Murphy, B. R., and Karpanty, S. M. 2012. Community-level waterbird responses to water hyacinth (*Eichhornia crassipes*). *Invasive Plant Science and Management* 5, 3: 353–362.

Waeber, P. O. and Hemelrijk, C. K. 2003. Female dominance and social structure in Alaotran gentle lemurs. *Behaviour* 140, 10: 1235–1246.

Wallace, A. P. C., Milner-Gulland, E. J., Jones, J. P. G., Bunnefeld, N., Young, R. E. 2015. Quantifying the short-term costs of conservation interventions for fishers at Lake Alaotra, Madagascar. *PLoS ONE* 10, 6: 1–15.

WHO 2011. Guidelines for drinking-water quality - 4th ed. *World Health Organization Press*, Geneva, Switzerland. 564 pp.

Wilmé, L. 1994. Status, distribution and conservation of two Madagascar bird species endemic to Lake Alaotra: Delacour's grebe *Tachybaptus rufolavatus* and Madagascar pochard *Aythya innotata*. *Biological Conservation* 69, 1: 15–21.

Yu, K. L. and Woo, N. Y. S. 1985. Effects of ambient oxygen tension and temperature on the bimodal respiration of an air-breathing teleost, *Channa maculata*. *Physiological Zoology* 58, 2: 181–189.

3.8 Appendix

Appendix 1. Mean, standard deviation (SD) and range (Min., Max.) of the water parameters at the three study sites with different level of degradation.

Appendix 2. Mean, standard deviation (SD), and range (Min., Max.) of the water parameters measured within the open water at Vohimarina during the four daily periods.

Appendix 3. Mean, standard deviation (SD), and range (Min., Max.) of the water parameters measured within the open water at Andreba during the four daily periods.

Appendix 4. Mean, standard deviation (SD), and range (Min., Max.) of the water parameters measured within the open water at Anororo during the four daily periods.

Appendix 5. Plant species, growth forms, site specific and plant species cover in %.

Appendix 6. Shown are means and standard deviation of the vertical vegetation density at the three sites.

Appendix 7. Shown are means and standard deviation of the vertical vegetation density of the lake shore vegetation at the three sites.

Appendix 8. Shown are means and standard deviation of the vertical vegetation density on the open water at the three sites.

Chapter 4

The challenges of community-based conservation in developing countries — a case study from Lake Alaotra, Madagascar

Pina Lena Lammers, Torsten Richter, Maren Lux, Jonah Ratsimbazafy,
Jasmin Mantilla-Contreras

Journal for Nature Conservation (2017), 40: 100 –112

Abstract

Nature conservation in tropical developing countries is particularly challenging as the human population is highly dependent on natural resources. Several approaches, such as small-scale, community-based conservation projects aiming to generate benefits for the community, have been applied to alleviate poverty and at the same time promote conservation. In Madagascar such projects are considered a promising alternative as large-scale conservation often fails. However, few evaluations to date have analyzed both ecological and socio-economic aspects. Our study focuses on the ecological and socio-economic aspects of a small-scale, community-based conservation project, called 'Park Bandro', at Lake Alaotra, Madagascar. At first glance, the area seems to conserve its natural flora and fauna. However, closer examination shows that the park suffers from isolation, disconnectivity and illegal activities, while its management suffers from an unequal distribution of benefits and a lack of recognition at community level. We use our results to discuss where challenges arise and to draw recommendations which will be relevant beyond Lake Alaotra. We show that institutional settings can foster the detachment of local management associations from the community and facilitate elite capture. Existing conflicts of interests and a lack of transparency in administration hinders long-term success. The managerial framework needs to be revised and adapted to foster capacity building, providing a basis for negotiation with the community and the integration of different social groups.

Keywords: community-based natural resource management, developing countries, mismanagement, small-scale protected area, institutional settings, elite capture

4.1. Introduction

Much of the world's biodiversity is found in developing countries in the tropics (Myers et al. 2000). In most of these countries people depend directly on natural resources to secure their subsistence. Thus, pressure on ecosystems is very high and nature conservation is a particular challenge. The prevailing low standards of living in developing countries mean that governments focus on economic growth rather than on nature conservation issues (Roe 2008). Numerous interlinked causes (e.g. political instability, poverty, low literacy rates, poor infrastructure and rapid human population growth) make nature conservation in low-income countries an arduous task (Parks and Harcourt 2002, Newmark 2008, Butsic et al. 2012, Wegmann et al. 2014), and legislation alone often fails to ensure effective management and enforcement of appropriate nature conservation acts (Rakotomanana et al. 2013). Consequently, many protected areas in developing countries exist only on maps and in laws (so-called ‘paper parks’), and offer little protection for biodiversity in practice (Bruner et al. 2001).

The conflict between economic and ecological interests is particularly apparent in Madagascar, one of the poorest countries in the world which at the same time accommodates unique biodiversity and an exceptionally high level of endemism (Myers et al. 2000, Rakotomanana et al. 2013), and is thus also described as “*one of the world’s hottest hotspot*[s]” (Ganzhorn et al. 2001, p. 1). Madagascar is plagued with an environmental crisis characterized by the overexploitation of natural resources, slash-and-burn agriculture, invasive species, trading of wild species, ecosystem degradation by mining, a high deforestation rate, corruption and the political crisis of 2009 which suspended and slowed down environmental measures adopted earlier, and it is still reeling from the aftermath (Barrett et al. 2010, Rakotomanana et al. 2013, Schwitzer et al. 2014).

Over the last three decades the idea of linking conservation and development has been embedded in global policy frameworks, notably the Convention on Biological Diversity and the Millennium Development Goals (Chandra and Idrisova 2011, Sachs 2012). The shift toward a conservation strategy incorporating poverty alleviation emerged in Madagascar with the implementation of the Durban vision, starting in 2004. The traditional conservation policy of strictly protected areas (IUCN category Ia, II, IV) was extended by the establishment of multiple-use protected areas (IUCN category III, V, VI) (Gardner et al. 2013). The new protected area system permits the sustainable use of natural resources by the local community (Virah-Sawmy et al. 2014), thereby safeguarding local livelihoods. In the past, the exclusion of the human population from strictly protected areas led, particularly in developing countries, to an overall net negative impact of protected areas on the local population (Naughton-Treves et al. 2005, Gardner et al. 2008).

Several conservation management approaches such as ICDPs (integrated conservation and development projects) and CBNRM (community-based natural resource management) have been implemented (Gardner et al. 2013, Pollini et al. 2014) in attempts to further rural development and alleviate poverty while preserving protected areas and decentralizing management rights from central government to local communities. Community-based nature conservation aims to encourage small communities to take responsibility for the development and sustainability of the natural resources on which their livelihoods depend (Pollini et al. 2014). With the GELOSE law (*Gestion Locale Sécurisée*) in 1996 the Malagasy government provided a legal framework for the devolution of natural resource management to the local communities. In 2000 a decree, named GCF (*Gestion Contrualisée des Forêts*) was amended to pay special attention to forest management transfer (Fritz-Vietta et al. 2009, Pollini 2011, Pollini et al. 2014).

However, the community-based concept itself entails many – often overlooked – aspects that may impede or thwart conservation efforts. (i) A community, as a small spatial and quantity unit with territorial affiliation is only capable of managing local and relatively small areas, which may not be consistent with the requisite size for the conservation goals. (ii) It is often falsely assumed that the community is socially homogeneous: people may differ in term of assets, income, ethnicity, religion, social class and language (Agrawal and Gibson 1999). These social disparities may complicate interactions and collective decisions within the community regarding natural resource use. (iii) Shared community norms can further support behavior which facilitates resource management but can also foster exploitive behavior (Agrawal and Gibson 1999). (iv) Finally, the distribution of power and interests at local level is decisive for conservation efforts: multiple actors with various interests, institutional arrangements as well as mechanisms governing the interrelations between actors have to be considered (Koku and Gustafsson 2003, Pretty 2003, Brooks et al. 2004, Mansuri and Rao 2004, Fabricius and Collins 2007, Ban et al. 2013, Brooks et al. 2013). Following Blaikie (2006) "*many of the theoretical benefits of CBNRM operate at a 'small-scale' only*" (p. 1945). In contrast, global conservationists place their emphasis on large-scale conservation, since this approach implies not only the preservation of biodiversity (e.g. species populations, communities and habitats) but also secures important ecosystem functions and services (Soulé and Simberloff 1986, Schwartz 1999, Mortelliti et al. 2014). In reality, however, biodiversity is often restricted to sites where large reserves are not an option: in many cases, only small patches of natural habitat are left, remaining populations of endangered species are restricted to small areas, or financial and human resources are limited (Armsworth et al. 2011, Tulloch et al. 2015). Previous studies and management approaches have shown that endangered plant, invertebrate and small vertebrate species can often be successfully protected in small fragments of habitat (Shafer 1995, Schwartz 1999, Fischer and Lindenmayer 2002, Tscharntke et al. 2002, Laguna et al. 2004, Bodin et al. 2006, Miller et al. 2012) and even suggest that small habitat patches may host a higher species richness than large patches (Oertli et al. 2002, Rösch et al. 2015). These findings indicate that, although large reserves will remain the top priority for biodiversity conservation, small patches are often valuable complements (Bruner et al. 2004). Conservation management decisions must thus be taken on an individual basis taking the options and the conservation goals into regard.

One example of natural resource management transfer to community level in Madagascar was the establishment of a small conservation area, Park Bandro, at Lake Alaotra in 2004 (Ratsimbazafy et al. 2013). The primary goal of this community park is the conservation of the locally endemic and critically endangered Alaotran gentle lemur (*Hapalemur alaotrensis*, locally called 'Bandro'), which is among the worlds 25 most endangered primates and places Lake Alaotra among 30 priority sites for lemur conservation (Schwitzer et al., 2013, 2015). The largest subpopulation of Alaotra gentle lemurs is found near the village Andreba Gara in one of the last intact vegetation patches which nowadays constitutes the Park Bandro (Schwitzer et al., 2013, 2015). The park faces conflicting interests between biodiversity conservation and the needs of a poor subsistence-driven agricultural society. The community park is part of the Lake Alaotra wetlands, one of the multiple-use protected areas in Madagascar (Virah-Sawmy et al. 2014), enduring high human demands on freshwater resources. The drastic growth of the local population over the past 50 years (Gardner 2011) has had detrimental effects on the entire ecosystem and resulted in highly fragmented wetland vegetation. The low social resilience of the rural population due to total dependency on natural resources, combined with political instability, a weak executive and high corruption levels impede the implementation and the enforcement of conservation management practices.

Using Park Bandro as a case study, we evaluated the efficiency of a small-scale protected area regarding its (i) habitat quality for the Alaotran gentle lemur, (ii) socio-economic influence on the local community and (iii) acceptance by local villagers. Habitat quality was assessed by floristic composition, vegetation physiognomy and plant coverage as determinants for the locomotion potential, food availability and retreat opportunities for the Alaotran gentle lemur. To appraise whether the park maintains better habitat quality than areas without community protection, its vegetation was compared with that of an adjacent area outside its boundaries. The socio-economic influence on the local community and its acceptance among the local population were investigated by conducting structured interviews with local stakeholders which addressed the financial income generated by the park, distribution of benefits and villagers' personal attitude towards the park.

4.2. Material and methods

4.2.1 Study system

The surroundings of Park Bandro: Park Bandro (S17 37.515 E48 29.933) is part of the freshwater marsh belt of Lake Alaotra, Madagascar's biggest lake, located in the northeast of the country (Copsey et al. 2009) (Figure 4.1.). The Lake Alaotra wetlands are seasonally flooded and grass-dominated freshwater marshes (Lammers et al. 2015) consisting of rooted vegetated islands dominated by papyrus (*Cyperus papyrus* subsp. *madagascariensis*) and reed (*Phragmites australis*) as well as floating vegetation. Invasive species like the water hyacinth *Eichhornia crassipes* and the floating ferns *Salvinia* spp. are altering the natural vegetation (Mutschler 2003). The seasonal flooding regime stimulates wetland use during the dry season, in particular the physically accessible vegetation fringes which serve as grazing grounds or are partially burned and converted into rice fields. Plants are also extracted for fodder or construction material.

In 2003 the Alaotra wetlands were designated as a RAMSAR site and in 2007 declared as a New Protected Area (*Nouvelle Aire Protégée*) by national law (Direction générale des forêts 2009, Dudley 2008). The New Protected Area as an IUCN category VI, emphasizes the sustainable use of natural resources by the villagers (Dudley 2008). To implement the New Protected Area several management zones were established at Lake Alaotra: (1) *Zone d'Utilisation Contrôlée* (ZUC), allowing controlled natural resource utilization with respect to either the (1a) extraction of marsh vegetation or (1b) fishing within the marshes; and (2) the *Zone Prioritaire de Conservation* (ZPC) defining core zones (2a) within the marshes for the conservation of the lemur population (*Hapalemur alaotrensis*) and (2b) at the lake for fish stock recovery. Park Bandro is classified as ZPC (Direction générale des forêts 2009) within the New Protected Area.

Conservation and management status of Park Bandro: Park Bandro is a locally organized protected area on a small scale, comprising less than 85 ha (Ratsimbazafy et al. 2013). The community park was established in 2004 as an initiative of the NGO Durrell Wildlife Conservation Trust Madagascar to regulate access to an area which is of particular relevance. It harbors the biggest subpopulation (up to 170 individuals; Ratsimbazafy et al. 2013) of the Alaotran gentle lemur (*Hapalemur alaotrensis*), which lives exclusively in the reed and papyrus beds surrounding Lake Alaotra (Mutschler and Tan 2003, Guillera-Arroita et al. 2010a, Ratsimbazafy et al. 2013). The French acronyms for VOI are CLB (*Communauté locale de base*) or COBA (*Communauté de base*), depending on whether management transfer is under the GCF law (COBA) or the Gelose law (CLB) (Dolch et al. 2015). The management rights for the marshes of Andreba Gara (235 ha) were officially devolved to the village-based association for forest management (VOI) in 2001 under the GCF law (CIREF 2002). The VOI is responsible for the control and restoration of the marshes, the seizure of illegally exploited resources in Park Bandro, the cleaning of the canals within the marshes, enabling tourists to visit the park by boat, the delimitation of the different management zones, the mediation of conflicts between the members and the delivery of a six-monthly report to the regional water and forest department CIREF (*Circonscription des Eaux et Forêts*). The VOI rely on their membership fees (0.12 USD per person in 2002) for their income, supplemented by revenue from imposed fines (e.g. accessing Park Bandro; hunting, grazing, fishing, cultivating and marsh burning in the park; 0.62 - 31 USD in 2002) (CIREF 2002).

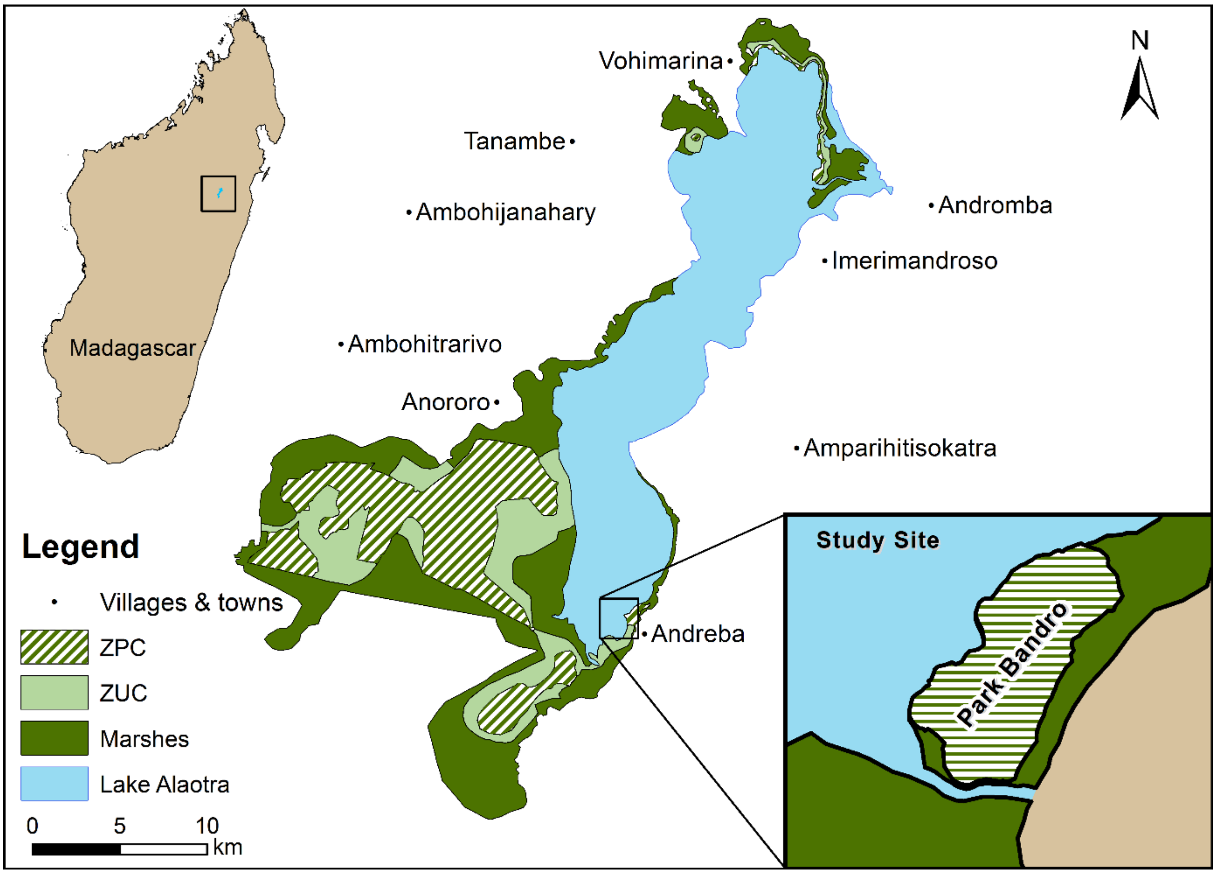

Figure 4.1. Map of Lake Alaotra and its wetland zonation (ZPC = *Zone Prioritaire de Conservation*, ZUC = *Zone d'Utilisation Contrôlée*). Park Bandro (PB) is located southeast of Lake Alaotra, near the village Andreba Gara.

A small group, named CFL (*Comité Forestier Local*) also monitors the park. The CFL was established in the main villages around the lake to monitor the marshes. The members are trained in monitoring the marshes and fish catch and remunerated by Durrell (Ratsimbazafy et al. 2013). The park gave rise to a small sector of eco-tourism (Camp Bandro, run by the NGO 'Madagascar Wildlife Conservation') which offers accommodation for tourists and organizes tours through the park. Guides, carrying out tourist tours, must be officially registered and participate in trainings by the Andasibe Guide Association.

Habitat requirements of the Alaotran gentle lemur: The Alaotran gentle lemur has a specialized folivorous diet, comprising only around 10 plant species. Individuals feed mainly on the papyrus *Cyperus papyrus* subsp. *madagascariensis*, the reed *Phragmites australis* and the grass

Echinochloa pyramidalis (Mutschler et al. 1998). The marsh-dwelling lemur is able to swim but avoids doing so; it needs contiguous dense vegetation to leap and move along (Guillera-Arroita et al. 2010a). The territorial lemur has a small home range (0.6–8 ha) and group size (around 3 individuals) (Mutschler et al. 1998, Nievergelt et al. 1998, Ratsimbazafy et al. 2013). Two criteria were used to assess the overall efficiency of the community Park Bandro: vegetation surveys were conducted to assess habitat quality; interviews were carried out to appraise the park's socio-economic influence on the local community and their attitude towards the park.

4.2.2. Habitat quality assessment

Vegetation surveys: To evaluate the habitat quality of Park Bandro, vegetation inside was compared with vegetation outside of the park. For this purpose, surveys were carried out from May until June 2014 when vegetation cover is expected to be highest due to high primary production after inundation. Plots of 100 m^2 were set up inside Park Bandro (PB, 21 plots) and a neighboring area outside the park, within the marsh belt of Andreba Gara (OA, 21 plots). The size of all plots was based on previously performed minimum area determination. The two areas (OA and PB) were assumed to be well comparable due to their similar location (left and right of the main canal leading from the village through the marsh belt to the lake) and distance to the village which exposes them to the same accessibility and degree of potential human influence. As indicators of disturbance, vegetation cover and structure were assessed Since these may vary due to several factors (e.g. human accessibility, nutrient input), plots in- and outside Park Bandro were located along three transects, each positioned parallel to the lakeshore: one along the marginal vegetation on the landward side, one along the marginal vegetation on the lakeward side and one inside the marsh belt (Figure 4.2.). The outside area is broader than Park Bandro due to the fact that a larger distance between transects inside of the marsh belt and those in the margins of the marsh belt is needed to take edge effects into account. Along each transect, data were recorded in seven plots, maintaining a minimal distance of 90 m between plots. Vegetation cover (%), vertical thickness of vegetation (%) and species cover (%) were assessed using the Londo-scale (Londo 1976). Moreover, water depth (cm) and maximum vegetation height (cm) were recorded. Altitude and geographical position were determined using a GPS (Garmin eTrex, WGS 84). Plant species were identified with the help of the herbarium of the *Parc Botanique et Zoologique de Tsimbazaza* in Antananarivo, Madagascar.

Figure 4.2. Study design: In Park Bandro (PB) and the outside area (OA), 42 plots of 100 m^2 each, were established along three transects (seven per transect), with a minimum distance of 90 m between them. Transects were positioned along the marginal vegetation on the landward and on the lakeward side as well as in the middle of the marsh belt.

Data analyses: To compare vegetation characteristics between Park Bandro (PB) and the outside area (OA), the Mann-Whitney U test was applied using R (Version 3.1.2). A TWINSPAN analyses was used to determine a clustering of the vegetation data, based on similarities and dissimilarities in species composition (Hill and Šmilauer 2005), a) between Park Bandro and the area outside; and b) between the locations of the plots within the marsh belt (middle, on the lakeward and on the landward side). For this purpose, data were classified in JUICE (Tichý 2002) using the modified TWINSPAN algorithm according to (Roleček et al. 2009). The cluster division was based on Whittaker's beta-diversity of species cover data (for detailed information about adjustments of the TWINSPAN see Appendix 9.).

4.2.3. Socio-economic influence of and attitude towards Park Bandro

Interviews: Structured interviews were conducted with the local population in Andreba Gara in December 2015 to determine (i) which stakeholders profit financially or suffer a disadvantage from Park Bandro, (ii) which stakeholders have non-financial benefits through Park Bandro (iii) the attitudes of the local stakeholders in regard to Park Bandro. Two groups were specified and addressed in the interviews: local stakeholders who are at least theoretically involved in the management and direct conservation practices in Park Bandro (Group 1; e.g. members of local conservation associations) and local stakeholders not directly involved with park management but who might be affected by the park since they work within its perimeter (Group 2). From the 4800 inhabitants of the village Andreba Gara a number of 183 inhabitants were beforehand identified to belong to Group 1: VOI members, Madagascar Wildlife Conservation members and employees, tourist guides as well as villagers renting out their boats for tourist's trips inside the park (personal communication with Fokontany, Madagascar Wildlife Conservation and VOI in Andreba; December 2015). Depending on availability and presence n = 49 persons out of group 1 were interviewed representing 28%. A similar sample size of n = 52 villagers was interviewed from the comparison group 2, including fishermen and rice cultivators. Since the exact number of locals affected by Park Bandro is not known, the interviewer sought out individuals meeting our criteria (e.g. at the local market or harbor) until a comparable sample size to group 1 was reached. Interviews were conducted by a familiar local villager in their homes to increase the interviewees' confidence (Group 1 = 13 questions, Group 2 = 12 questions; see Appendix 10. for complete questionnaires). Multiple answers were possible for some questions.

Data analyses: Income data obtained from structured interviews are given in US Dollar (USD) using the exchange rate of December 2015 (MGA/USD = 3201), the time period when interviews were conducted. Data about income not generated by Park Bandro were removed from the dataset (e.g. NGO employees whose income is paid by transfer payments from foreign countries). When information about income was given in harvested amount of rice (in tons or number of bags) the total cash income was calculated using the local prices in 2013 (1 rice bag = 50 kg = 55,000 MGA; 1 kg = 1100 MGA) based on oral information from T. Rakotoarisoa (personal communication, March 16, 2016). Earnings referring to more than one source of income were excluded (n = 1) when calculating income per person and income source.

4.3. Results

4.3.1. Habitat quality assessment

Although plant species richness was lower in Park Bandro (22 species) than in the outside area (29 species), the overall results provide evidence for more intact vegetation and hence, a higher habitat quality within the park boundaries (see Appendix 11. for full data and plant list). Several indicators underline this observation: the species composition in the small-scale conservation area differs significantly from that in the outside area. The vegetation of the community park is denser and higher, and the endemic liana *Argyreia vahibora* represents a large proportion of vegetation cover. In contrast, outside the park the proportion of invasive species cover is higher (Figures 4.3. and 4.4.). Besides, the area of open water in the outside area is higher, reflecting the destruction of the surface vegetation.

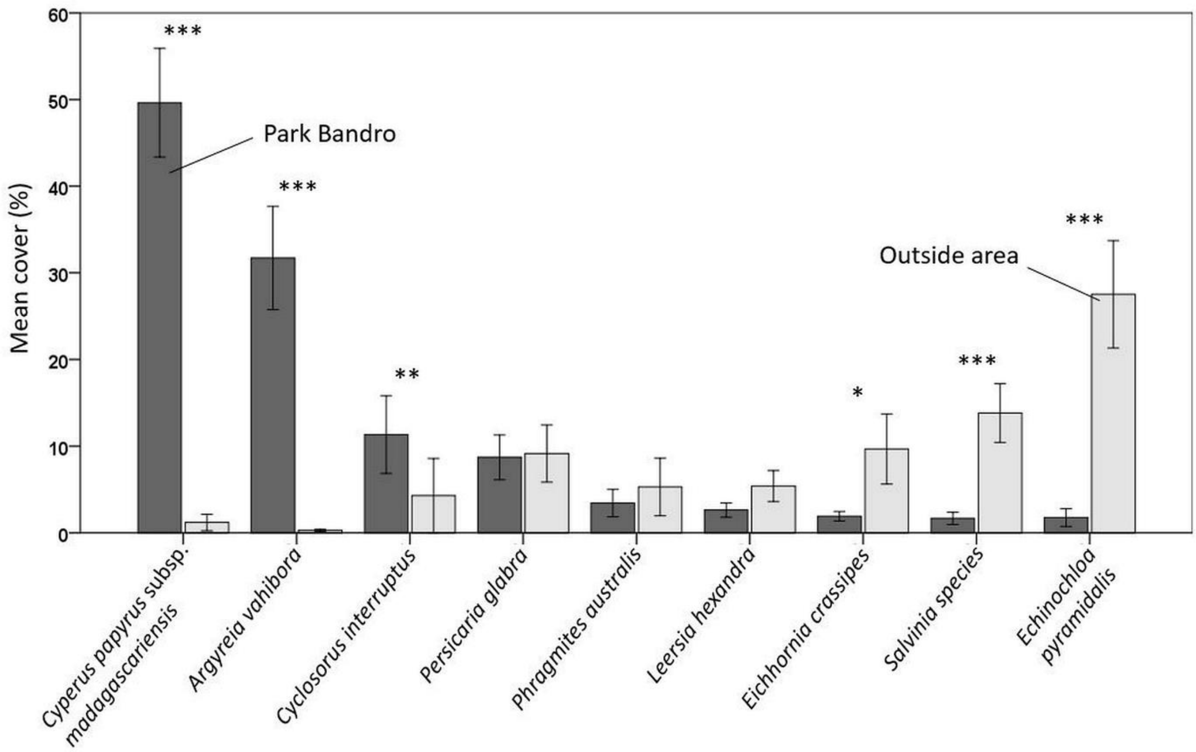

Figure 4.3. Most dominant plant species (mean cover ≥5%) in Park Bandro (n = 21) and the outside area (n = 21). Bars (mean ± SE) with asterisks indicate statistical differences for species cover between the Park Bandro and the outside area using the Mann-Whitney-U test (significance level: *p≤ 0.05, **p < 0.01, ***p < 0.001).

The PB and OA each have a distinct plant species composition; they have no dominant species in common and the most dominant species in each area occurs significantly less frequently in the respective other area (Figure 4.3.). Whereas the vegetation of Park Bandro is dominated by a plant species endemic to Madagascar (*Argyreia vahibora*, 32%) and by species characteristic for the Alaotra wetlands (Pidgeon 1996) (the papyrus *Cyperus papyrus* subsp. *madagascariensis*, 50% and the fern *Cyclosorus interruptus*, 11%), about one quarter of the outside area is dominated by invasive species (the water hyacinth *Eichhornia crassipes*, 9.7%; and the floating ferns *Salvinia* spp., 14%) (Figure 4.3.). In the small-scale conservation area the proliferation of invasive species is minimal (2.9%). Further, endemic plant species hardly occur outside the park (OA = 0.4%, PB = 25%) (Figure 4.4.).

The described plant species composition has various consequences for the habitat quality for the Alaotran gentle lemur. The two most dominant plant species of the Park Bandro, the papyrus and the liana, build the upper vegetation layer and therefore ensure sufficient vegetation rigidity and height for the lemurs' locomotion above the water surface. Besides, the papyrus plant is one of the species' major food sources. Outside the community-managed area the vegetation is dominated by the antelope grass *Echinochloa pyramidalis* (28% cover) which also provides a food source for the endemic lemur but, unlike the papyrus and the liana with their lignified stem cells, cannot provide the necessary stable and high habitat structure.

The predominance of papyrus and the liana in Park Bandro results in a significantly higher and denser vegetation structure (Figure 4.5.), as average plant height for papyrus is about 4 m and average stem length about 10–20 m for the liana (Deroin 2001, Terer et al. 2012). The vegetation within the park is generally one third higher than in the outside area (PB = 365 cm, OA = 250 cm, $p = 0.023$).

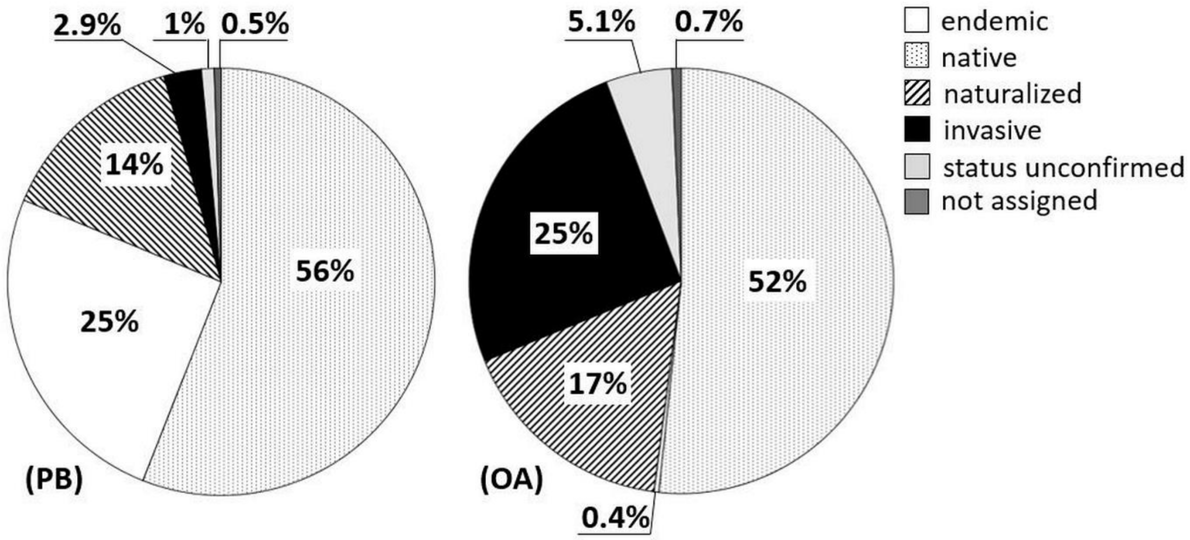

Figure 4.4. Plant composition of Park Bandro (PB) and the outside area (OA) by distribution status class (%) (not assigned = assignment to distribution status group was not possible on a generic level).

The differences in vertical density of the vegetation between the park and the outside area become especially evident with increasing vegetation height (20–30 cm: $p = 0.005$; 30–50 cm: $p = 0.003$; 50–300 cm: $p \leq 0.001$; Figure 4.5.; Appendix 12.). Another vital characteristic of the community-managed park is its significantly higher vegetation cover compared to the area outside (PB = 92%, OA = 76%, $p = 0.005$) as well as the small proportion of open water areas (4.8%). Outside the park, almost one quarter of the area is without plant cover (open water area = 21%), which makes it difficult or impossible for the Alaotran gentle lemur to cross these areas.

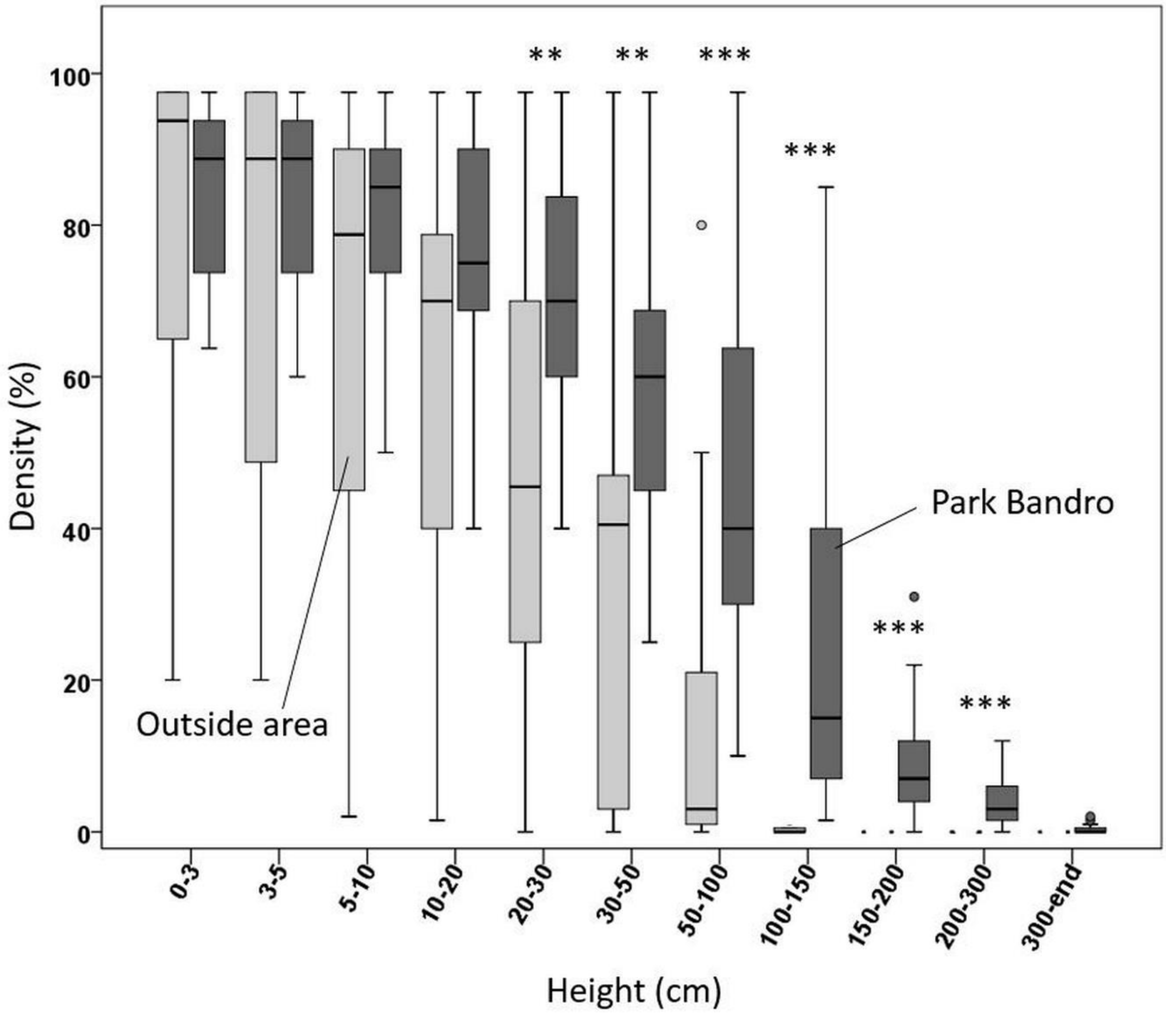

Figure 4.5. Vertical vegetation density (%) in Park Bandro (n = 21) and the outside area (n = 21) at different heights (Box–whisker plots show median, upper and lower quartiles, and minimum and maximum values). Asterisks indicate statistical differences for vegetation density between Park Bandro and the outside area using the Mann-Whitney-U test (significance level: *$p \leq 0.05$, **$p < 0.01$, ***$p < 0.001$).

Differences in species composition between Park Bandro and the outside area: The TWINSPAN analysis confirmed the differences between the community-managed park and the outside area in regard to plant species composition: the first and most distinctive division separated almost all of the plots within Park Bandro (group 1–3) from the outside area (group 4–6). Only two plots each from the park and the outside area, were assigned to the respective other group (Figure 4.6.). Overall, the 42 plots were classified into six species assemblages. The species assemblage of groups 1–3 is characterized by species which are typical for the Alaotra wetlands (*Cyperus papyrus* subsp. *madagascariensis*, *Argyreia vahibora* and *Cyclosorus interruptus*) (Pidgeon 1996). Groups 4–6 are distinguished by species which typically occur in open water areas (*Nymphaea lotus*) or can quickly occupy open areas (*Eichhornia crassipes*, *Salvinia* spp., *Echinochloa pyramidalis*), indicating the higher proportion of open water surface in this area.

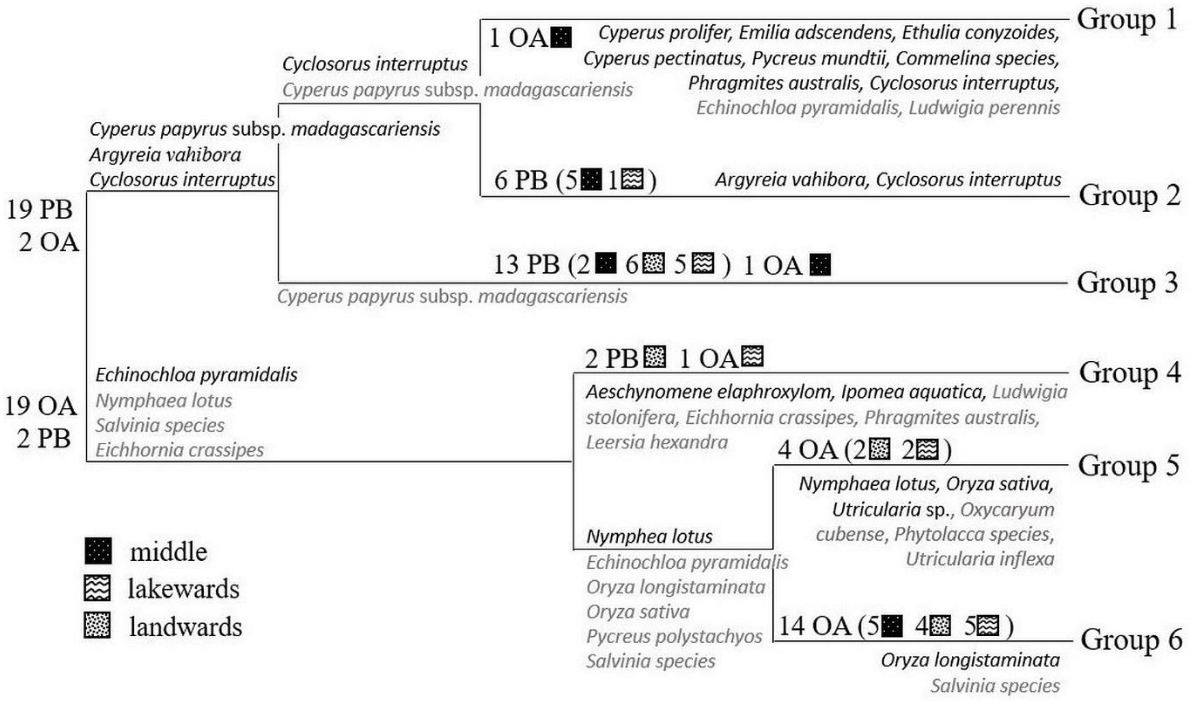

Figure 4.6. Dendrogram obtained from TWINSPAN classification of Park Bandro (PB, n = 21) and the outside area (OA, n = 21) based on plant species composition. Character species at each division are shown (black = fidelity ≥50%, grey = fidelity ≥40%). Values before the boxes indicate the number of plots at each location (along the marginal vegetation on the landward and on the lakeward side, in the middle of the marsh belt).

The second division tends to separate plots along the transects in the middle of the marsh belt (groups 1 and 2) from plots in the marginal vegetation: plots in the inner marsh belt (groups 1 and 2) are separated from group 3 due to the high occurrence of the fern *Cyclosorus interruptus*, whilst in group 3 *Cyperus papyrus* subsp. *madagascariensis* and *Argyreia vahibora* are the predominant plant species. The third division separated group 1 (a plot of the outside area) from group 2, which comprised, in contrast to group 1, stands of the endemic Convolvulaceae *Argyreia vahibora*. Group 4 (inter alia containing two plots in Park Bandro) is distinguished from groups 5 and 6, which have common indicator species like the water lily (*Nymphaea lotus*) and agriculturally used rice species (*Oryza* spp.).

4.3.2. Socio-economic influence of and attitude towards Park Bandro

A total of 101 interviews were conducted with the local residents of Andreba Gara: age, sex and profession were similar for both groups of interviewees (Table 4.1.). The median age was around 41 years and more than two thirds of the respondents were men. Most persons interviewed were fisherman (n = 60) followed by cultivators (n = 14) (Table 4.1.). Group 1 comprised primarily VOI members (n = 33) but also guides (n = 6), boat drivers (n = 2), boat renters (n = 2), Madagascar Wildlife Conservation employees (n = 2) and members (n = 7) (Table 4.1.).

Table 4.1. Age, sex and profession for group 1 (directly or indirectly involved in conservation management and practices for Park Bandro, n = 52) and group 2 (local stakeholders that might be affected by the establishment of the park, n = 49) as well as information about the assignment of people from group 1 to the different associations and practices related to Park Bandro conservation management.

		Group 1 (n= 52)	Group 2 (n= 49)
Age (median, range)		45 (23-93)	40 (25-78)
Sex (n)	m	38	35
	w	14	14
Profession (n)	cook	2	3
	cultivator	9	5
	cultivator & fisherman	2	2
	fisherman	30	30
	fishtraider	3	5
	guard	2	0
	handicraft woman	2	2
	housewife	0	1
	seamstress	0	1
	teacher	2	0
Assignment of group 1 (n)	guide	6	-
	boat driver	2	-
	boat renting	2	-
	MWC empolyee	2	-
	MWC member	7	-
	VOI memeber	33	-

Sources and distribution of income: Interviews revealed that 69 of the 101 interviewees used Park Bandro before its foundation, mostly for fishing (n = 49). However, only 12 interviewees claimed financial losses because of the establishment of the park. 33 of all interviewees have financial income generated by the park (Table 4.2.). Income can be generated by legal and illegal activities. 13 sources of income are legal and related to ecotourism inside Park Bandro (guiding, boat rental and cleaning); nearly double the number of income sources (n = 21) are from illegal activities inside the park. 16 persons gave detailed information about their income per year generated by the park: 22 USD per person was earned by legal activities in Park Bandro (n = 8; ranging from 5 USD to 31 USD; Table 4.2.) whilst 238 USD per person was made by illegal activities (n = 8; ranging from 16 USD to 1031 USD). While guiding was the major source of legal income (n = 6), rice cultivation constituted the main source of illegal income (n = 10; Table 4.2.). A higher proportion of individuals in group 1 (n = 26) obtained income generated by the park than individuals in group 2 (n = 6).

Within group 1, the people who benefit are mainly VOI members (n = 14), and guides (n = 6). The proportion of illegal sources of income was highest for VOI members (11 of 14), Madagascar Wildlife Conservation members (n = 3, all) and group 2 (6 of 7) (Table 4.3.).

Table 4.2. Source and distribution of income generated by Park Bandro. Of 33 people confirming that they have income, only 16 specified the amount. The number of respondents considered for calculation of annual income per person is given in brackets (Group 1: directly or indirectly involved in conservation management and practices for Park Bandro, n = 52; group 2: local stakeholders that might be affected by the establishment of the park, n = 49)

	Respondents (n)		Annual income per person (USD)	Range (USD)
Financial income (n= 101)	33		130 (n=16)	2-1031
Group 1 (n= 52)	26		138 (n=10)	5-1031
Group 2 (n= 49)	7		117 (n=6)	16-344
Legal activities	*Group 1*	*Group 2*		
Guiding	6	-	30 (n=5)	25-31
Boat driver	4	-	6 (n=1)	-
Rent boat	2	-	5 (n=1)	-
Cleaning boats	-	1	16 (n=1)	-
Annual income by legal activities			**22 (n=8)**	5-31
Illegal avtivities	*Group 1*	*Group 2*		
Fishing	4	1	62 (n=1)	-
Rice cultivation	6	4	362 (n=5)	94-1031
Harvesting papyrus (handicrafts)	3	1	16 (n=2)	-
Clearing vegetation	2	-	n.d.	-
Annual income by illegal activities			**238 (n=8)**	16-1031

Notes: Sample size= 101, average response number per person= 1, range= 1-2.

Attitudes of local stakeholders towards Park Bandro: Most of the interviewed people (n = 98) have already seen the Alaotran gentle lemur. One tenth (n = 12) of the interviewees were not aware of the ban on natural resource exploitation inside of Park Bandro. Reasons given by the interviewees for refraining from exploitation of the park's resources are, first of all, its protected status (Group 1: n = 27; Group 2: n = 10) followed by the absence of reasons for exploiting the park's resources (Group 1: n = 13; Group 2: n = 17) and the fear of being discovered by villagers and exposed to their gossip (Group 1: n = 6; Group 2: n = 9) or, to a minor extent, of being punished by the police (Group 1: n = 3; Group 2: n = 4). When asked about the groups profiting from the park, most of the respondents (n = 141) referred to associations and institutions (primarily to the VOI and Guides). In comparison, few respondents referred to resource users (n = 32) and the community or region (n = 31; Figure 4.7.).

Table 4.3. Number of legal and illegal sources of income for interviewees in groups 1 and 2, i.e. local stakeholders with and without direct involvement in park management and conservation practices, respectively.

		Sources of income (n)		Interviewees (n)
		Legal	Illegal	
Group 1	Guide	1	6	6
	Boat driver	0	1	1
	Rent boat	0	1	1
	MWC employee	0	1	1
	MWC member	3	0	3
	VOI member	11	3	14
	Group 2	1	6	7

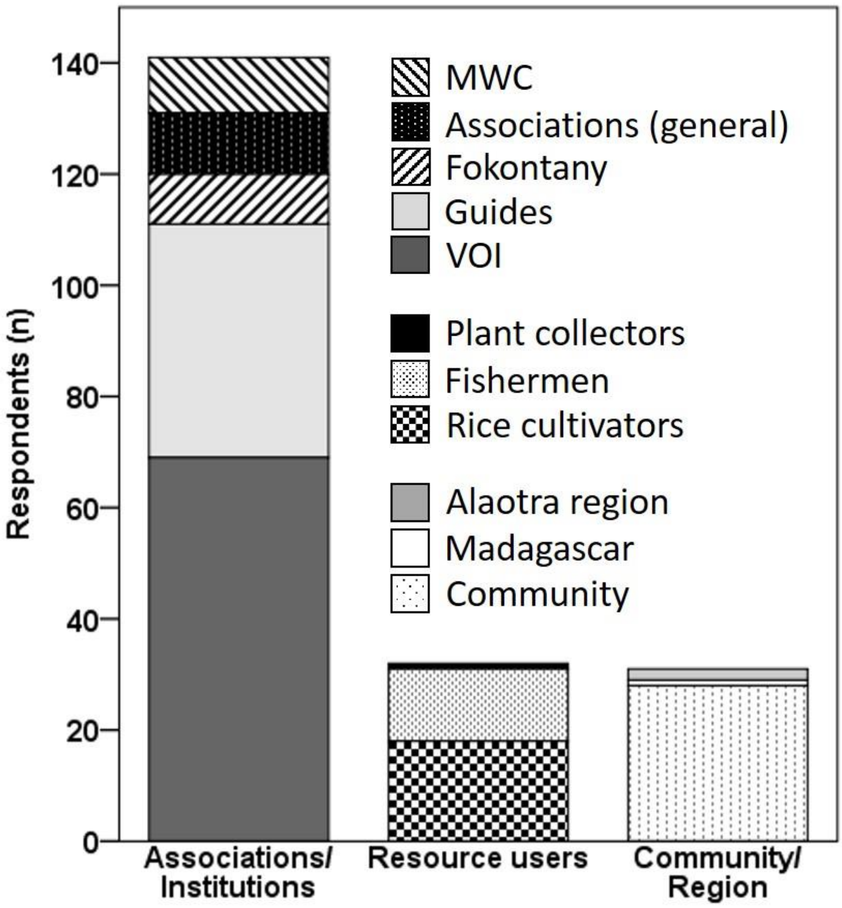

Figure 4.7. Groups profiting from Park Bandro according to interviewees (n = 100) (multiple answers possible, average response number per person = 2, range = 1–4).

Nearly one quarter of the interviewees (n = 22) argued that Park Bandro is of no importance for them. The reason given for rejection of the park was that they do not benefit from it. When the interviewees crediting the park with importance (n = 79) were asked about their personal benefit from Park Bandro, nearly half of the respondents (n = 35) listed its biodiversity as being the main benefit (natural richness, n = 19; Alaotran gentle lemur, n = 13; preservation of fish population, n = 3). Economic profit was named by 30 respondents (personal profit, n = 17; profit for the community, n = 8; attracting tourists, n = 5) and socio-cultural benefits by 14 (pride and popularity of the community, n = 11; personal development, cooperation possibilities, contact with foreigners, n = 1 each).

4.4. Discussion

Habitat quality: Although Lake Alaotra is officially protected as a Ramsar site and New Protected Area (*Nouvelle Aire Protégée*), nature conservation fails on a large scale, as most areas of the lake are already degraded (Lammers et al. 2015) and conservation restrictions are not clear and/or not respected. However, our study shows that small-scale conservation areas can be a valuable option for human-dominated landscapes with high natural resource dependencies. The community-managed Park Bandro represents an island in a relatively degraded environment. Our habitat quality results show that the vegetation is more intact inside the park than outside and thus represents a better habitat for the Alaotran gentle lemur (*Hapalemur alaotrensis*): The community park comprises mature marsh vegetation, indicated by the lower plant diversity, and the increased canopy height and density (Pidgeon 1996). The closed vegetation and its high canopy offer retreats for animal species, nest sites for mammals and birds, and a higher locomotion potential for terrestrial species (Guillera-Arroita et al. 2010b, Pidgeon 1996). The closed vegetation layer characterizing the park also prevents the spreading of the invasive plant species which are present at Lake Alaotra (Theoharides and Dukes 2007, Van Kleunen et al. 2014). Additionally, more intact vegetation reduces habitat exposure and fragmentation, and sustains habitat connectivity. These are attributed to the small proportion of open water areas occurring in the park, and hence the maintenance of a closed vegetation cover.

The positive role in biodiversity conservation of the small protected area of Park Bandro seems to confirm the pattern observed worldwide: a study by Bodin et al. (2006) in southern Madagascar underlines in this context that in fragmented and human-dominated landscapes the geographical location of remnant vegetation patches may be of greater importance than their size. Likewise, Cowling and Bond (1991) demonstrated in a study in the Cape region of South Africa that 4–15 ha patches are sufficient to protect the region's flora. In the Valencian region in Spain small protected areas (2–20 ha) ensure the preservation of the region's flora. These plant micro-reserves supplement the large protected area network of the region in which 70% of the most endangered plant species are not found. In southern Sweden, Götmark and Thorell (2003) identified a size of only 1.6 ha for key forest habitats.

Conservation area scale – potentials and restrictions: The small size of Park Bandro offers certain advantages in terms of its management. Likewise, it offers enough habitat for species with a small home range like the Alaotran gentle lemur. However, in the long term there are limitations to the potential of a small park to fully implement the long-term conservation goals.

The community-based management approach itself restricts the size of a conservation area: fewer people can be involved and conservation areas have to be located on community territory (Agrawal and Gibson 1999, Kiss 2004, Blaikie 2006). In our case, Andreba Gara, a community comprising a human population of 4800 inhabitants, manages 235 ha of marshes (Andrianandrasana et al. 2005). Notwithstanding the limitations, a small size (of both the conservation area and management group) has been proven to facilitate decision-making when considering the dynamics of local cultural, socio-economic and political interests (Agrawal 2001, Brooks et al. 2013).

Our results suggest that Park Bandro may offer sufficient habitat and food to the current subpopulation of the Alaotran gentle lemur. This is based on the species' small home range and group size (Mutschler et al. 1998, Nievergelt et al. 1998, Ratsimbazafy et al. 2013) and by the dominance of its major food source (*Cyperus papyrus* subsp. *madagascariensis*) in the park (cf. Mutschler et al. 1998). Even though this study shows evidence of continuing illegal resource use within the community park, the high regeneration potential of the marsh vegetation (Mitsch and Gosselink 2000, Osumba et al. 2010, Opio et al. 2014) will, to a certain extent, compensate the ongoing human destruction inside the park.

However, long-term conservation targets, especially with respect to long-term species conservation, pose various problems. The main concern may not be the size of the park itself, but its connectivity within the surrounding matrix of human-used land.

An island in a human-dominated landscape: An evident problem of Park Bandro is human disturbance outside and nearby. Since most of the land is already claimed, people expand into the marsh belt to establish rice paddies (Waeber and Wilmé 2013). Starting already in the 90s at Lake Alaotra, the marsh conversion into rice fields flourished since 2007. The current development of changing rainfall patterns (a shorter and postponed rainy season) as well as the sedimentation of fields near the hills also cause the local farmers to move into the marshes of

Lake Alaotra. The pressure on the marshes is thus expected to increase in the future. Adjacent rice fields continuously downsize the preserved area as they spread further into the park. The non-existence of marked park boundaries facilitates the practice of agricultural land expansion. Our results further display a high contrast between the marsh vegetation of the protected Park Bandro and the surroundings, indicating the ever-increasing isolation of the park. Maiorano et al. 2008 suggested that "*small parks are not going to be viable in the long term if they are considered as islands surrounded by a 'human-dominated ocean*" (p. 1297). This is especially true for areas with high human population growth and land use intensity, as is the case for the Alaotra Region (Parks and Harcourt 2002, Newmark 2008, Butsic et al. 2012, Wegmann et al. 2014). Small conservation areas are more vulnerable to anthropogenic changes outside because a greater proportion of land borders the neighboring human-used areas (Brashares et al. 2001, Bodin et al. 2006, Maiorano et al. 2008, Lasky and Keitt 2013). A study by Lefèvre (2012) affirmed that the edges of Park Bandro are highly affected by invasive and fast-growing species to the detriment of the vegetation structure.

Hence, the park suffers from highly disrupted connectivity, presumably as a result of the human-induced changes of vegetation composition and cover outside the park. Changes in underlying ecological flows (Morris 2012) are one of the key problems affecting long-term conservation efforts for the Alaotran gentle lemur and its habitat. The fragmented and low-growing vegetation outside the park hampers the locomotion potential of this locally endemic lemur. Thus, gene flow between populations and escape of individuals in case of habitat destruction by fire, the main threat to the lemur, is impossible (Ratsimbazafy et al. 2013). At around 170 individuals, population density inside the park is already high and will inevitably lead to inbreeding, genetic drift, intraspecific competition and density stress, and finally decrease genetic diversity. In addition, plant dispersal and various other ecological processes are impaired due to the disrupted connectivity of Park Bandro.

Financial benefit – an empty promise? The results of the study indicate that the financial benefit from Park Bandro for the local community is low. 13 of 101 interviewed persons have direct financial revenue resulting from ecotourism. However, financial income is comparatively low with an average of 22 USD per person per year and differs notably between persons (yearly income from 5 USD to 31 USD). Even when considering that it was not possible to disclose either the entire sum of legal income generated by Park Bandro within this study or the sustainability of investments realized by legal earnings (Wunder 2000, Christ et al. 2003), the results reveal an overall low economic impact of the community park on local residents. A comparison with a recent study by (Rakotoarisoa et al. 2015), calculating a mean income of 2.5

USD per day for the Alaotra region, reflects that cash benefits from the park fall below the average regional income.

A comparison of financial data from 37 CBNRM (community-based natural resource management) projects conducted by Salafsky et al. (2001) showed that most projects produce at best a modest economic benefit (see also Magome and Fabricius 2004), but Kiss (2004) underlines that even small revenues are beneficial in poor regions. As Wunder (2000) articulates, "*Economic incentives are imperative for nature conservation, especially in remote and ill-monitored regions where a weak presence of the state hinders the use of alternative tools of environmental regulation*" (p. 465). According to Kiss (2004), financial benefits from conservation projects for local communities further support residents' attitudes towards conservation.

In contrast, a review of outcomes of community-based conservation projects by Turner et al. (2012) and Brooks et al. (2013) set out the minor importance of economic benefits for the success of a project. According to their studies project design (including skills and institutional capacity, equal benefit distribution, enhancement of social capital, local participation and integration of local culture, leaders and institutions) is critical for its success. Gruber (2010) found similar results when reviewing key characteristics of effective CBNRM. Although the success of the project is linked to a variety of factors, besides financial advantages, conservation incentives are likely to increase when at least some people of the community have financial benefits from the conservation area (Wunder 2000). For our study, nearly one quarter of the interviewees (n = 22) argued that Park Bandro is of no importance for them. Reasons given for rejection of the park include the lack of financial benefits, ascribed to inequitable distribution of earnings, as interviewees say that these are largely retained by the VOI (village-based association managing Park Bandro) and the Guides. Thus, the income level might be of less importance than sharing of financial benefit within the community (e.g. channel profits into community projects, provision of non-cash benefits). In some cases, conservation projects achieved participation of local residents without providing any financial incentives but by 'merely' matching indigenous values and practices with their project design and so gaining the legitimacy of local traditional leaders. An example given by the Zimbabwean CBNRM program CAMPFIRE demonstrates that the participation of people who are not receiving cash benefits is based on local social fabric and solidarity with local community but is not led by their conviction about the project's goals (Backson 2004, Sibanda 2004). Overall, the outcomes of this study conform with former evaluations of CBNRM projects, demonstrating that the belief in community-based conservation success depending on cash benefits might be too simplistic.

Community involvement – the way towards empowerment of the poor and local development?
The results of our study disclose that the majority of cash benefits generated by Park Bandro are made by illegal practices and by the local elite: it was found that the yearly income from illegal activities (rice cultivation and fishery) is much higher than income from legal activities, at 238 USD and 22 USD per person, respectively. We also noted that the majority of illegal earners are at the same time directly or indirectly involved in the management of the park. In theory, the punishment of illegal activities by imposing fines is part of the VOI's management plan but in practice seems to be rarely enforced. This implies that being a member of an association advocating the park's protection status does not necessarily mean an affirmative attitude towards the park. On the contrary, it even seems to be the prerequisite for extensive illegal activities inside the protected area.

Empowering poor people and local development are among the principle objectives of CBNRM in addition to protection of biodiversity and sustainable resource use (Dongier et al. 2002, USAID 2009, Dressler et al. 2010) However, reality shows that the exploitation of local resources and the alteration of power relations to the detriment of the poor often seem to be the bitter irony of CBNRM projects around the world (Mehta and Heinen 2001, Sibanda 2004, Blaikie 2006, Toillier et al. 2011, Enns et al. 2014, Neudert et al. 2017). We suggest that those obstacles to effective nature conservation management are rooted in the lack of congruence between local and global interests and in the associations' origin and settings. Although these interlinked aspects are common and much discussed threats for CBNRM projects, they are still largely neglected when planning and implementing CBNRM projects (Platteau and Gaspart 2003, Mansuri and Rao 2004, Red Cross and Red Crescent Societies 2014).

First, the global vision of linking conservation with development by community-led resource management is bond up with the non-negotiable component of restricting resource extraction. The mismatch of higher-level and local interests impedes fair compromises and often leads to the failure of projects. A study by Toillier et al. (2011) found, for example, that community-based forest management led farmers to intensify agriculture and move into previously forested land, because they had to compensate for the restrictions on resource use imposed by the new regulations. Even if the value of protected areas for local residents goes beyond financial profits (people in our study mentioned, for example, biodiversity, popularity and pride in the village), their everyday struggle for survival mostly prevents them from acquiring a long-term perspective in natural resource management. Second, principles of rural community governance are neglected. Although there exists a strong international awareness of rural community governance in Madagascar (communities being led and formed by traditionally embedded social and cultural values, and thus legitimation and decisions are regulated by the resulting social structure and solidarity), CBNRM associations (VOI or COBA) were created without any historical background or locally meaningful legitimation (Kull 2002). The resulting "*reshuffle*[ed] *control and access to resources*" (Pollini et al. 2014, p. 179) is often followed by a division of the community: in many cases the VOI members, due to the aforementioned membership restrictions, do not originate from the *fokon'olona* (decision makers of the community) and therefore do not necessarily include locally recognized members with experience in managing conflicts, but are seen as an arbitrary group that clutches power previously held by the *fokon'olona* (Pollini and Lassoie 2011, Pollini et al. 2014). As the VOI itself is often detached from community structures that warrant legitimation, the same holds true for the laws described in the VOI's resource management plan (Pollini and Lassoie 2011).

Third, certain factors which shape the pre-existing local power relations and lead to the economic and social marginalization of people within a community are often worsened when disregarded during development and implementation of projects (Mansuri and Rao 2004, Saito-Jensen et al. 2010). In rural areas, power relations are often based on land ownership (Red Cross and Red Crescent Societies 2014) but also shaped by religion, gender and ethnicity. In rural areas of Madagascar, the kinship network is an additional powerful force that offers solidarity (described by the Malagasy term '*fihavanana*') and ranks residents in a social hierarchy (Fritz-Vietta et al. 2011). Hence, solidarity and silence regarding ongoing illegal activities may be demanded by existing kinship network and other power systems.

Fourth, several institutional settings in Madagascar may further the reproduction of dominant power relations and a so-called 'tyranny of participation' (Cooke and Kothari 2001) rather than the distribution of power: i) Even though membership in the CBNRM associations is open to any residents within the territory new members must be accepted by existing members. ii) The CBNRM associations can create new management rules for their specific resources. Thus, as Pollini and Lassoie (2011) put it, "*Any group of people with common objectives can constitute a COBA* [or VOI]*, decide who will be in and out, and elaborate the rules that best match its interests*" (p. 6). iii) Participation is compounded by the fact that a higher literacy level is needed to understand the 'western- style' management plans and maps; less formally educated groups, including legitimized villagers such as the elders of the community, will be outcompeted by better educated stakeholders. iv) Lastly, weak external control makes it easier to extract natural resources. A general lack of financial and human resources in the Malagasy administration, as is the case in most developing countries, restricts their work efficiency (Froger and Méral 2012).

In conclusion, it can be stated that a minority of privileged stakeholders can easily take power over the CBNRM association, whilst their local power relations (e.g. family, lineage, property) within the community are likely to influence or restrict access to associations for marginal local groups and residents with conflicting interests (Dressler et al. 2010, Fritz-Vietta et al. 2011, Pollini and Lassoie 2011).

4.5. Conclusion and recommendations

Although the community-managed Park Bandro is at first glance able to successfully maintain an intact vegetation, regarding its long-term viability, local legitimacy and distribution of benefits it joins the ranks of a large number of CBNRM projects in developing countries (Platteau, 2004, Hockley and Andriamarovololona 2007, Dressler et al. 2010, Measham and Lumbasi 2013, Muyengwa et al. 2014). Key viability problems of small protected areas, such as our case study site that may hinder their long-term success are often the lack of connectivity and diminishing size (Seiferling et al. 2011). Elite capture, illegal activities within protected areas, small financial benefit and a gap between the community and the group managing the protected area are issues that are particularly widespread in developing countries in the tropics (Mansuri and Rao 2004, Platteau 2004, Brooks et al. 2013). In the following section we aim to present recommendations for the improvement of the management of small protected areas in low-income countries in general, as they often face common problems.

The isolation of protected areas within agricultural landscapes interrupts their ecological connectivity and, in the long run, thwarts the conservation of viable species populations (especially of mobile species). The establishment of additional protected areas in the vicinity enables these populations to migrate from disturbance and to retain genetic diversity. In such cases, the edges of protected areas are for the most part adjacent to agricultural areas. Consequently, implementing an additional buffer zone around the protected area always requires ecosystem restoration and may entail conflicts about land tenure. This reinforces the necessity of installing visible delimitation of the protected area borders to mitigate the 'seemingly randomly and unnoticed' spread of bordering cropland into it.

A lack of control (internal and external) and informal social structures enhance elite capture more strongly than formal structures among groups responsible for conservation management (e.g. associations). Capacity building for group leaders and members, including training in conflict solving and administration could help them to acquire more competence in the management of their association, to strengthen their active involvement (e.g. decision-making, preparing minutes from meetings) and to make members more accountable. The abilities acquired during such capacity training will help the association's members to follow and to understand agreements and hence to increase transparency. A "*sequential and conditional release of aid funds* [to] *discipline local leaders or intermediaries*" is recommended by Platteau (2004, p. 232). The right to remove leaders of an association from their position between the official elections (taking place every three years) curtails the leaders' power and can reduce risk of elite capture. Participation of different social groups from the community could, moreover, help to include marginal groups and to overcome the boundaries of hierarchies and inequality within the existing social structures.

Hockley and Andriamarovololona (2007) argue that the failure of the groups in charge of management leads to the disillusion of the community. A responsible group of people, who are more representative of the community as mentioned above is one step towards closing the gap between association and community. Further, we follow the request of Fritz-Vietta et al. (2011) that conservationists become acquainted with and apply "*unconventional means of* […] *local knowledge system*s" (p. 228) (e.g. dance, songs, storytelling, spiritual ceremonies) while using a "*clear language*" (Fritz-Vietta et al. 2011, p. 228). Furthermore, conservationists (e.g. NGO, policy makers) have to communicate openly about opportunity costs of the protected area and hence about the trade-offs of conservation (Fritz-Vietta et al. 2011, Measham and Lumbasi 2013, Pollini et al. 2014). By creating a fair basis for negotiation, the cornerstone is laid for a development away from top-down decision-making to the real empowerment of the community.

More transparency in administrative processes within the responsible group will hopefully lead to a more equal share of the revenues. Even small benefits for the community (e.g. little celebrations, one-time support of local institutions) could help to create positive attitudes towards the objectives of the protected area (Platteau 2004). Revenues from eco-tourism should (at least for protected areas in remote locations outside touristic areas) be considered as a small additional source of income for locals. Following Hockley and Andriamarovololona (2007) the focus of the benefits should include other approaches: the promotion of community pride, although insufficient on its own; the development of new products, which, the authors argue, should not be overestimated. The possibility of payments for ecosystem services or other compensation schemes are further important tools (Fabricius et al. 2004, Measham and Lumbasi 2013, Pollini and Lassoie 2011).

According to Elinor Ostrom, who received a Nobel prize in the management of common resources, communities succeed in managing common resources if the following design principles are fulfilled: 1) the resource user group as well as the boundaries of the resource itself must be clearly defined, 2) rules governing common resources must be congruent with local needs and conditions, 3) most individuals affected by those rules can participate in modifying the rules, 4) monitors who control resource condition and use are accountable to the other resource users or are resource users themselves, 5) resource users who violate the rules should be assessed by other resource users or officials accountable to them by applying graduated sanctions (depending on the seriousness and context of the offense), 6) resource users have rapid access to low-cost local arenas to resolve conflicts among them, 7) the right of the resource users to organize their own association is recognized by external authorities (local and governmental) (Ostrom 1990, Chapter 3). When applied to our case of Park Bandro, two facts become evident: first, management has failed to apply almost all the principles; second, almost all aspects addressed in Ostrom′s principles match the causes of mismanagement determined by our study.

The attainment of some principles (1 and 5) can be remedied comparatively easily because the reasons for their non-implementation are either a lack of financial resources or non-compliance. The subsequent realization of principles 2, 3 and 7, however, is a particular challenge. The content of these principles normally forms the basic framework of a project since consideration and participation of the local populations is a prerequisite for legitimation. A subsequent decision to respect these principles could, on the one hand, result in a change in the project's overriding goals, but an ongoing disregard would most likely lead to the collapse of the project.

Genuine support for the project by the local community will be the most important condition which needs to be fulfilled to realize Ostrom principle 4 and 6: the investment of time for resource monitoring, the attachment of greater weight to the rules established to achieve the project's goals than to the rules determining local structures; and the consultation of recognized community members experienced in conflict solving.

In summary, laying the base for a management which represents a genuine alternative for the local communities and restricts illegal activities within the community-managed protected areas requires greater transparency and participation, in order to form a more representative group of leaders; as well as conservationists from outside that grant the community their real autonomy.

4.6. Acknowledgement

We thank the community of Andreba Gara for their cooperation and hospitality, Lala Nomenjanahary Elysé and Bernard Aimé Rajaonarivelo for their assistance with field work and the Durrell Wildlife Conservation Trust in Ambatondrazaka for supporting this work. The research was funded by the Bauer-Stiftung (Deutsches Stiftungszentrum).

4.8. References

Agrawal, A. and Gibson, C. C. 1999. Enchantment and disenchantment: the role of community in natural resource conservation. *World Development* 27, 4: 629–649.

Agrawal, A. 2001. Common property institutions and sustainable governance of resources. *World Development* 29, 10: 1649–1672.

Andrianandrasana, H. T., Randriamahefasoa, J., Durbin, J., Lewis, R. E. and Ratsimbazafy, J. H. 2005. Participatory ecological monitoring of the Alaotra wetlands in Madagascar. *Biodiversity and Conservation* 14, 11: 2757–2774.

Armsworth, P. R., Cantú-Salazar, L., Parnell, M., Davies, Z. G. and Stoneman, R. 2011. Management costs for small protected areas and economies of scale in habitat conservation. *Biological Conservation* 144, 1: 423–429.

Backson, S. 2004. Community wildlife management in Zimbabwe: The case of CAMPFIRE in the Zambezi Valley. In: *Rights, resources and rural development: Community-based natural resource management in southern Africa*. C. Fabricius, E. Koch, H. Magome and S. Turner (eds.), pp 248–258. Routledge, London and Sterling.

Ban, N. C., Mills, M., Tam, J., Hicks, C. C., Klain, S., Stoeckl, N. et al. 2013. A socialecological approach to conservation planning: embedding social considerations. *Frontiers in Ecology and the Environment* 11, 4: 194–202.

Barrett, M. A., Brown, J. L., Morikawa, M. K., Labat, J.-N. and Yoder, A. D. 2010. CITES designation for endangered rosewood in Madagascar. *Science* 328, 5982: 1109–1110.

Blaikie, P. 2006. Is small really beautiful? Community-based natural resource management in Malawi and Botswana. *World Development* 34, 11: 1942–1957.

Bodin, Ö., Tengö, M., Norman, A., Lundberg, J. and Elmqvist, T. 2006. The value of small size: loss of forest patches and ecological thresholds in southern Madagascar. *Ecological Applications* 16, 2: 440–451.

Brashares, J. S., Arcese, P. and Sam, M. K. 2001. Human demography and reserve size predict wildlife extinction in West Africa. *Proceedings of the Royal Society: Biological Sciences* 268, 1484: 2473–2478.

Brooks, M. L., D'Antonio, C. M., Richardson, D. M., Grace, J. B. and Keeley, J. E. 2004. Effects of invasive alien plants on fire regimes. *Bioscience* 45, 7: 677–688.

Brooks, J., Waylen, K. and Mulder, M. 2013. Assessing community-based conservation projects: a systematic review and multilevel analysis of attitudinal, behavioral, ecological, and economic outcomes. *Environmental Evidence* 2, 1: 2.

Bruner, A. G., Gullison, R. E., Rice, R. E. and Da Fonseca, G. A. 2001. Effectiveness of parks in protecting tropical biodiversity. *Science* 291, 5501: 125–128.

Bruner, A. G., Gullison, R. and Balmford, A. 2004. Financial costs and shortfalls of managing and expanding protected-area systems in developing countries. *Bioscience* 54, 12: 1119–1126.

Butsic, V., Radeloff, V. C., Kuemmerle, T. and Pidgeon, A. M. 2012. Analytical solutions to trade-offs between size of protected areas and land-use intensity. *Conservation Biology* 26, 5: 883–893.

CIREF 2002. Antontan-taratasy mikasika ny fifanekena famindram-piandraiketam-pitantanana ny loharanon-karena voajanahary zetra amińny vondrońolona ifotony (Gestion contrualisée des forêts). *Circonscription Régionale des Eaux et Forêts*, Ambatondrazaka, Madagascar. 30 pp.

Chandra, A. and Idrisova, A. 2011. Convention on biological diversity: a review of national challenges and opportunities for implementation. *Biodiversity and Conservation* 20, 14: 3295–3316.

Christ, C., Hillel, O., Matus, L. and Sweeting, J. 2003. Tourism and biodiversity: mapping tourism's global footprint. *Conservation International*, Washington, DC. 66 pp.

Cooke, B. and Kothari, U. 2001. *Participation: The new tyranny?* Zed Books, London. 207 pp.

Copsey, J. A., Jones, J. P., Andrianandrasana, H., Rajaonarison, L. H. and Fa, J. E. 2009. Burning to fish: local explanations for wetland burning in Lac Alaotra, Madagascar. *Oryx* 43, 3: 403–406.

Cowling, R. M. and Bond, W. J. 1991. How small can reserves be? An empirical approach in Cape Fynbos, South Africa. *Biological Conservation* 5, 83: 243–256.

Deroin, T. 2001. Famille 71. Convolvulaceae. In : *Flore de Madagascar et des Comores*. P. Morat (ed.), pp 11–287. Muséum National d'Histoire Naturelle, Paris.

Direction générale des forêts 2009. Elaboration du plan de gestion du site Ramsar d'Alaotra. *Ministère de l'environnement, des forêts et du tourisme*, Antananarivo, Madagascar. 120 pp.

Dolch, R., Ndriamiary, J., Ratolojanahary, T., Randrianasolo, M. and Ramanantenasoa, I. A. 2015. Improving livelihoods, training para-ecologists, enthralling children: earning trust for effective community-based biodiversity conservation in Andasibe, eastern Madagascar. *Madagascar Conservation and Development* 10,1: 21–28.

Dongier, P., Van Domelen, J., Ostrom, E., Ryan, A., Wakeman, W. et al. 2002. Community-driven development. In: *Empowerment and poverty reduction: A sourcebook*. D. Narayan (ed.), pp 301–331. World Bank, Washington, DC.

Dressler, W., Büscher, B., Schoon, M., Brockington, D. A., Hayes, T. et al. (2010). From hope to crisis and back again? A critical history of the global CBNRM narrative. *Environmental Conservation* 37, 1: 5–15.

Dudley, N. 2008. Guidelines for applying protected area management categories. *IUCN*, Gland, Switzerland. 86 pp.

Enns, C., Bersaglio, B. and Kepe, T. 2014. Indigenous voices and the making of the post- 2015 development agenda: the recurring tyranny of participation. *Third World Quarterly* 35, 3: 358–375.

Fabricius, C. and Collins, S. 2007. Community-based natural resource management: governing the commons. *Water Policy* 9, Suppl. 2, 83–97.

Fabricius, C., Koch, E., Turner, S., Magome, H. and Sisitka, L. 2004. Conclusions and recommendations: what we have learned from a decade of experimentation. In: *Rights, resources and rural development: community-based natural resource management in southern Africa*. C. Fabricius, E. Koch, H. Magome and S. Turner (eds.), pp 271–281. Routledge, London and Sterling.

Fischer, J. and Lindenmayer, D. B. 2002. Small patches can be valuable for biodiversity conservation: two case studies on birds in southeastern Australia. *Biological Conservation*, 106, 1: 129–136.

Fritz-Vietta, N. V. M., Röttger, C. and Stoll-Kleemann, S. 2009. Community-based management in two biosphere reserves in Madagascar – distinctions and similarities: what can be learned from different approaches? *Madagascar Conservation and Development* 4, 2: 86–97.

Fritz-Vietta, N. V. M., Ferguson, H. B., Stoll-Kleemann, S. and Ganzhorn, J. U. 2011. Conservation in a biodiversity hotspot: insights from cultural and community perspectives in Madagascar. In: *Biodiversity hotspots: distribution and protection of conservation priority areas*. F. E. Zachos and J. C. Habel (eds.), pp 209–233. Springer, Berlin.

Froger, G. and Méral, P. 2012. Towards an institutional and historical analysis of environmental policy in Madagascar. *Environmental Science and Policy* 22, 5: 369–380.

Götmark, F. and Thorell, M. 2003. Size of nature reserves: densities of large trees and dead wood indicate high value of small conservation forests in southern Sweden. *Biodiversity and Conservation* 12, 6: 1271–1285.

Ganzhorn, J. U., Lowry, P. P., Schatz, G. E. and Sommer, S. 2001. The biodiversity of Madagascar: one of the world's hottest hotspots on its way out. *Oryx* 35, 4: 1–3.

Gardner, C. J., Ferguson, B., Rebara, F. and Ratsifandrihamanana, N. 2008. Integrating traditional values and management regimes into Madagascar's expanded protected area system – the case of Ankodida. In: *Protected landscapes and cultural and spiritual values*. J.-M. Mallarach (ed.), pp 92–103. Kasparek, Heidelberg.

Gardner, C. J., Nicoll, M. E., Mbohoahy, T., Oleson, K. L. L., Ratsifandrihamanana, A. N. et al. 2013. Protected areas for conservation and poverty alleviation: experiences from Madagascar. *Journal of Applied Ecology* 50, 6: 1289–1294.

Gardner, C. J. 2011. IUCN management categories fail to represent new, multiple-use protected areas in Madagascar. *Oryx* 45, 3: 336–346.

Gruber, J. S. 2010. Key principles of community-based natural resource management: A synthesis and interpretation of identified effective approaches for managing the commons. *Environmental Management* 45, 1: 52–66.

Guillera-Arroita, G., Lahoz-Monfort, J. J., Milner-Gulland, E. J., Young, R. P. and Nicholson, E. 2010a. Monitoring and conservation of the critically endangered Alaotran gentle lemur *Hapalemur alaotrensis*. *Madagascar Conservation and Development* 5, 2: 103–109.

Guillera-Arroita, G., Lahoz-Monfort, J. J., Milner-Gulland, E. J., Young, R. P. and Nicholson, E. 2010b. Using occupancy as a state variable for monitoring the critically endangered Alaotran gentle lemur *Hapalemur alaotrensis*. *Endangered Species Research* 11, 2: 157–166.

Hill, M. O. and Šmilauer, P. 2005. TWINSPAN for windows version 2.3. *Centre for Ecology and Hydrology* and *University of South Bohemia*, Ceske Budejovice, CZ. 29 pp.

Hockley, N. J. and Andriamarovololona, M. M. 2007. The economics of community forest management in Madagascar: is there a free lunch? *USAID*, Antananarivo. 81 pp.

Kiss, A. 2004. Is community-based ecotourism a good use of biodiversity conservation funds? *Trends in Ecology and Evolution* 19, 5: 232–237.

Koku, J. E. and Gustafsson, J.-E. 2003. Local institutions and natural resource management in the South Tongu District of Ghana: a case study. *Sustainable Development* 11, 1: 17–35.

Kull, C. A. 2002. Empowering pyromaniacs in Madagascar: ideology and legitimacy in community-based natural resource management. *Development and Change* 33, 1: 57–78.

Laguna, E., Deltoro, V., Pèrez-Botella, J., Pèrez-Rovira, P., Serra, L. et al. 2004. The role of small reserves in plant conservation in a region of high diversity in eastern Spain. *Biological Conservation* 119, 3: 421–426.

Lammers, P., Richter, T., Waeber, P. O. and Mantilla-Contreras, J. 2015. Lake Alaotra wetlands: how long can Madagascar's most important rice and fish production region withstand the anthropogenic pressure. *Madagascar Conservation and Development* 10, S3: 116–127.

Lasky, J. R. and Keitt, T. H. 2013. Reserve size and fragmentation alter community assembly, diversity, and dynamics. *The American Naturalist* 182, 5: 142–160.

Lefèvre, M. 2012. An analysis of the edge effect in the protected wetland of Lac Alaotra. Unpublished case study. *SIT Madagascar*, Fort Dauphin, Madagascar. 45 pp.

Londo, G. 1976. The decimal scale for releves of permanent quadrats. *Vegetatio* 33, 1: 61–64.

Magome, H. and Fabricius, C. (2004). Reconciling biodiversity conservation with rural development: The holy grail of CBNRM. In: *Rights, resources and rural development: community-based natural resource management in southern Africa*. C. Fabricius, E. Koch, H. Magome and S. Turner (eds.), pp 93–111. Routledge, London and Sterling.

Maiorano, L., Falcucci, A. and Boitani, L. 2008. Size-dependent resistance of protected areas to land-use change. *Proceedings of the Royal Society: Biological Sciences* 275, 1640: 1297–1304.

Mansuri, G. and Rao, V. 2004. Community-based and -driven development: a critical review. *The World Bank Research Observer* 19, 1: 1–39.

Measham, T. G. and Lumbasi, J. A. 2013. Success factors for community-based natural resource management (CBNRM): lessons from Kenya and Australia. *Environmental Management* 52, 3: 649–659.

Mehta, J. N. and Heinen, J. T. 2001. Does community-based conservation shape favorable attitudes among locals? An empirical study from Nepal. *Environmental Management* 28, 2: 165–177.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A. and Kent, J. 2000. Biodiversity hotspots for conservation priorities. *Nature* 403, 6772: 853–858.

Miller, J. R., Morton, L. W., Engle, D. M., Debinski, D. M. and Harr, R. N. 2012. Nature reserves as catalysts for landscape change. *Frontiers in Ecology and the Environment* 10, 3: 144–152.

Mitsch, W. J. and Gosselink, J. G. 2000. The value of wetlands: importance of scale and landscape setting. *Ecological Economics* 35, 1: 25–33.

Morris, K. 2012. Wetland connectivity: understanding the dispersal of organisms that occur in Victoria's wetlands. *Technical Report No. 225*, Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg, Victoria. 56 pp.

Mortelliti, A., Sozio, G., Driscoll, D. A., Bani, L., Boitani, L. et al. 2014. Population and individual-scale responses to patch size, isolation and quality in the hazel dormouse. *Ecosphere* 5, 9: 1–21.

Mutschler, T. and Tan, C. L. 2003. *Hapalemur*, bamboo or gentle lemur. In: *The natural history of Madagascar*. S. M. Goodman and J. P. Benstead (eds.), pp 1324–1329. University of Chicago Press, Chicago.

Mutschler, T., Feistner, A. T. C. and Nievergelt, C. M. 1998. Preliminary field data on group size, diet and activity in the Alaotran gentle lemur *Hapalemur griseus alaotrensis*. *Folia Primatologica* 69, 5: 325–330.

Mutschler, T. 2003. Lake Alaotra. In: *The natural history of Madagascar*. S. M. Goodman and J. P. Benstead (eds.), pp 1530–1534. University of Chicago Press, Chicago.

Muyengwa, S., Child, B. and Lubilo, R. 2014. Elite capture: a comparative case study of meso-level governance in four southern Africa countries. In: *Adaptive cross-scalar governance of natural resources*. B. Child and G. Barnes (eds.), pp 179–202. Routledge, London, UK.

Naughton-Treves, L., Holland, M. B. and Brandon, K. 2005. The role of protected areas in conserving biodiversity and sustaining local livelihoods. *Annual Review of Environment and Resources* 30, 1: 219–252.

Neudert, R., Ganzhorn, J. U. and Watzold, F. 2017. Global benefits and local costs – the dilemma of tropical forest conservation: a review of the situation in Madagascar. *Environmental Conservation* 44, 1: 82–96.

Newmark, W. D. 2008. Isolation of African protected areas. *Frontiers in Ecology and the Environment* 6, 6: 321–328.

Nievergelt, C. M., Mutschler, T. and Feistner, A. T. C. 1998. Group encounters and territoriality in wild Alaotran gentle lemurs (*Hapalemur griseus alaotrensis*). *American Journal of Primatology* 46, 3: 251–258.

Oertli, B., Joye, D. A., Castella, E., Juge, R., Cambin, D. and Lachavanne, J.-B. 2002. Does size matter? The relationship between pond area and biodiversity. *Biological Conservation* 104, 1: 59–70.

Opio, A., Jones, M. B., Kansiime, F. and Otiti, T. 2014. Growth and development of *Cyperus papyrus* in a tropical wetland. *Open Journal of Ecology* 4, 3: 113–123.

Ostrom, E. 1990. *Governing the commons*. Cambridge University Press, Cambridge. 280 pp.

Osumba, J. J. L., Okeyo-Owuor, J. B. and Raburu, P. O. (2010). Effect of harvesting on temporal papyrus (*Cyperus papyrus*) biomass regeneration potential among swamps in Winam Gulf wetlands of Lake Victoria Basin, Kenya. *Wetlands Ecology and Management* 18, 3: 333–341.

Parks, S. A. and Harcourt, A. H. 2002. Reserve size, local human density, and mammalian extinctions in U.S. protected areas. *Conservation Biology* 16, 3: 800–808.

Pidgeon, M. 1996. An ecological survey of Lake Alaotra and selected wetlands of central and eastern Madagascar in analyzing the demise of Madagascar pochard *Aythya innotata*. *WWF/Missouri Botanical Garden*, Antananarivo, Madagascar. 139 pp.

Platteau, J.-P. and Gaspart, F. 2003. The risk of resource misappropriation in communitydriven development. *World Development* 31, 10: 1–28.

Platteau, J.-P. 2004. Monitoring elite capture in community-driven development. *Development and Change* 35, 2: 223–246.

Pollini, J. and Lassoie, J. P. 2011. Trapping farmer communities within global environmental regimes: the case of the GELOSE legislation in Madagascar. *Society and Natural Resources* 24, 8: 814–830.

Pollini, J., Hockley, N. and Muttenzer, F. D. 2014. The transfer of natural resource management rights to local communities. In: *Conservation and environmental management in Madagascar*. I. R. Scales (ed.), pp. 172–192. Routledge, Oxon and New York.

Pollini, J. 2011. The difficult reconciliation of conservation and development objectives: The case of the Malagasy Environmental Action Plan. *Human Organization* 70, 1: 74–84.

Pretty, J. 2003. Social capital and the collective management of resources. *Science* 302, 5652: 1912–1914.

Rösch, V., Tscharntke, T., Scherber, C. and Batáry, P. 2015. Biodiversity conservation across taxa and landscapes requires many small as well as single large habitat fragments. *Oecologia* 179, 1: 209–222.

Rakotoarisoa, T. F., Waeber, P. O., Richter, T. and Mantilla-Contreras, J. 2015. Water hyacinth (*Eichhornia crassipes*), any opportunities for the Alaotra wetlands and livelihoods? *Madagascar Conservation and Development* 10:128–136.

Rakotomanana, H., Jenkins, R. K. B. and Ratsimbazafy, J. 2013. Conservation challenges for Madagascar in the next decade. In: *Conservation Biology: voices from the tropics*. N. S. Sodhi, L. Gibson and P. H. Raven (eds.), pp. 33–39. John Wiley and Sons, Chichester.

Ratsimbazafy, J. H., Ralainasolo, F. B., Rendigs, A., Mantilla-Contreras, J., Andrianandrasana, H. et al. 2013. Gone in a puff of smoke? *Hapalemur alaotrensis* at great risk of extinction. *Lemur News* 17: 14–18.

Red Cross and Red Crescent Societies 2014. World disasters report: focus on culture and risk. *International Federation of Red Cross* and *Red Crescent Societies*, Geneva, Switzerland, pp. 276.

Roe, D. 2008. The origins and evolution of the conservation-poverty debate: a review of key literature, events and policy processes. *Oryx* 42, 4: 491–503.

Roleček, J., Tichý, L., Zelený, D. and Chytrý, M. 2009. Modified TWINSPAN classification in which the hierarchy respects cluster heterogeneity. *Journal of Vegetation Science* 20, 4: 596–602.

Sachs, J. D. 2012. From millennium development goals to sustainable development goals. *The Lancet* 379, 9832: 2206–2211.

Saito-Jensen, M., Nathan, I. and Treue, T. 2010. Beyond elite capture? Community-based natural resource management and power in Mohammed Nagar village, Andhra Pradesh, India. *Environmental Conservation* 37, 3: 327–335.

Salafsky, N., Cauley, H., Balachander, G., Cordes, B., Parks, J. et al. 2001. A systematic test of an enterprise strategy for community-based biodiversity conservation. *Conservation Biology* 15, 6: 1585–1595.

Schwartz, M. W. 1999. Choosing the appropriate scale of reserves for conservation. *Annual Review of Ecology and Systematics* 30: 83–108.

Schwitzer, C., Mittermeier, R. A., Davies, N., Johnson, S., Ratsimbazafy, J. et al. 2013. Lemurs of Madagascar — a strategy for their conservation 2013-2016. *IUCN SSC Primate Specialist Group*, *Bristol Conservation and Science Foundation,* and *Conservation International*, Arlington, VA.

Schwitzer, C., Mittermeier, R. A., Johnson, S. E., Donati, G., Irwin, M., et al. 2014. Conservation. Averting lemur extinctions amid Madagascar’s political crisis. *Science* 343, 6173: 842–843.

Schwitzer, C., Mittermeier, R. A., Rylands, A. B., Chiozza, F., Williamson, E. A. et al. 2015. Primates in peril: The worlds 25 most endangered primates 2014–2016. *IUCN SSC Primate Specialist Group, International Primatological Society, Conservation International*, and *Bristol Zoological Society*, Arlington, VA.

Seiferling, I. S., Proulx, R., Peres-Neto, P. R., Fahrig, L. and Messier, C. 2011. Measuring protected-area isolation and correlations of isolation with land-use intensity and protection status. *Conservation Biology* 26, 4: 610–618.

Shafer, C. L. 1995. Values and shortcomings of small reserves: dealing with the smallest habitat fragments when some of them are all that is left. *Bioscience* 45, 2: 80–88.

Sibanda, B. 2004. Community wildlife management in Zimbabwe: the case of CAMPFIRE in the Zambezi Valley. In: *Rights, resources and rural development: community-based natural resource management in southern Africa*. C. Fabricius, E. Koch, H. Magome and S. Turner (eds.), pp. 248–258. Routledge, London and Sterling.

Soulé, M. E. and Simberloff, D. 1986. What do genetics and ecology tell us about the design of nature reserves? *Biological Conservation* 35, 1: 19–40.

Terer, T., Triest, L. and Muthama Muasya, A. 2012. Effects of harvesting Cyperus papyrus in undisturbed wetland, Lake Naivasha, Kenya. *Hydrobiologia* 680, 1: 135–148.

Theoharides, K. A. and Dukes, J. S. 2007. Plant invasion across space and time: factors affecting nonindigenous species success during four stages of invasion. *New Phytologist* 176, 2: 256–273.

Tichý, L. 2002. JUICE, software for vegetation classification. *Journal of Vegetation Science* 13, 3: 451.

Toillier, A., Serpantié, G., Hervé, D. and Lardon, S. 2011. Livelihood strategies and land use changes in response to conservation: pitfalls of community-based forest management in Madagascar. *Journal of Sustainable Forestry* 30, 1–2: 20–56.

Tscharntke, T., Steffan-Dewenter, I., Kruess, A. and Thies, C. 2002. Contribution of small habitat fragments to conservation of insect communities of grassland-cropland landscapes. *Ecological Applications* 12, 2: 354–363.

Tulloch, A. I. T., Barnes, M. D., Ringma, J., Fuller, R. A., Watson, J. E. M. et al. 2015. Understanding the importance of small patches of habitat for conservation. *Journal of Applied Ecology* 53: 418–429.

Turner, W. R., Brandon, K., Brooks, T. M., Gascon, C., Gibbs, H. K. et al. 2012. Global biodiversity conservation and the alleviation of poverty. *Bioscience* 62, 1: 85–92.

United States Agency for International Development 2009. Environmental guidelines for small scale activities in Africa. *Environmentally Sound Design and Management Capacity Building for Partners and Programs in Africa (ENCAP)*, Washington, DC.

Van Kleunen, M., Dawson, W. and Maurel, N. 2014. Characteristics of successful alien plants. *Molecular Ecology* 24, 9: 1954–1968.

Virah-Sawmy, M., Gardner, C. J. and Ratsifandrihamanana, A. N. 2014. The Durban Vision in practice: experiences in the participatory governance of Madagascar's new protected areas. In: *Conservation and environmental management in Madagascar*. I. R. Scales (ed.), pp. 216–251. Routledge, Oxon and New York.

Waeber, P. O. and Wilmé, L. 2013. Madagascar rich and intransparent. *Madagascar Conservation and Development* 8, 2: 52–54.

Wegmann, M., Santini, L., Leutner, B., Safi, K., Rocchini, D. et al. 2014. Role of African protected areas in maintaining connectivity for large mammals. *Philosophical Transactions of the Royal Society of London: Biological Sciences* 369, 1643: 20130193.

Wunder, S. 2000. Ecotourism and economic incentives — an empirical approach. *Ecological Economics* 32, 3: 465–479.

Further reading:

Kull, C.A., Tassin, J., Moreau, S., Rakoto Ramiarantsoa, H., Blanc-Pamard, C. et al. 2012. The introduced flora of Madagascar. *Biological Invasions* 14, 4: 875–888.

4.9 Appendix

Appendix 9. Adjustments of the modified TWINSPAN Analyses following Roleček et al. (2009).

Appendix 10. Questionnaires.

Appendix 11. Table shows the recorded plant species in Park Bandro (PB) and the outside area (OA), the mean ± SE for vegetation cover (%), maximum vegetation height (cm) and species cover (%), the significance values (p) for statistical comparisons between Park Bandro (BP) and the outside area (OA) as well as the species distribution and status.

Appendix 12. Table shows the mean ± SE for vertical density (%) and the significance values (p) for statistical comparisons between Park Bandro (PB) and the outside area (OA).

Chapter 5

From safety net to point of no return — is small-scale inland fishery reaching its limits?

Pina Lena Lammers, Torsten Richter, Jasmin Mantilla-Contreras

Global Environmental Change, submitted

Abstract

Small-scale inland fishery is a livelihood opportunity for millions of people in developing countries but still poorly integrated in policy and research. Understanding the economic, ecological, political and social impacts local fishermen are coping with as well as their vulnerability and perception of change can clarify weaknesses, gaps and challenges in the current fishery management and help decision makers to develop appropriate adaptation strategies. Using the small-scale fishery at Lake Alaotra, Madagascar, as an example we analyzed the current development and fishers' perception of and adaption strategies to changes. We surveyed fish catches to assess the current state of the fish stocks and performed interviews to gain understanding about fishers' livelihood, problems, behavior and attitudes.

Our results show, that the fishery sector of Lake Alaotra has grown dramatically although fish catches have fallen sharply. Species composition changes and low reproduction rates are reflecting the fishing pressure. Local fishers are mainly part-time fishers, as decreasing agricultural yields and lacking agricultural land make livelihood diversification necessary. A point of no return is indicated by a raising number of fishermen even in the light of the fact of fishers' negative perspective on the future of fishery, the disliked idea of their sons becoming fishermen, the variety of challenges fishers are facing (e.g. declining catches, high workload) and full-time fishers' willingness to exit fishery which is hampered by a lack of assets.

Lake Alaotra seems to reflect an alarming trend which can be seen in many regions of the world already and may affect a larger number in the near future. The Alaotran fishery demonstrates that small-scale fishery's ability to provide livelihoods will become increasingly important. It further highlights that the identification of ongoing livelihood dynamics in order to disclose possible poverty trap mechanisms and to understand fisheries current function is essential for local management orientation and the understanding of management failures.

Keywords: small-scale fishery, livelihood opportunity, welfare function, developing countries, Madagascar, Africa

5.1. Introduction

Small-scale inland fishery (SSIF) is a growing livelihood opportunity for people living next to water bodies in developing countries (Béné and Friend 2009, Youn et al. 2014, FAO 2016). In many local communities in the developing world, fish is the primary source of protein, being critically important for human health and child development (Youn et al. 2014). Today, over 90 percent of the world's capture fishers are employed in small-scale fisheries, providing food and nutrition security as well as cash income to local communities in the developing world (Welcomme et al. 2010, FAO 2015, Lynch et al. 2016). In developing countries SSIF and related activities provide employment for 60 million people (World Bank 2012). However, SSIF, as fisheries in general, are increasingly facing challenges, e.g. growing demand, environmental degradation and climate change (Allan et al. 2005, Chuenpagdee 2012, Lam et al. 2012) that may endanger fishery-based livelihoods worldwide and calls for particular attention in decision-making processes and adapted management of resources. Nevertheless, small-scale fisheries are poorly integrated in regional and national policy as well as scientific research (Béné and Friend 2011, World Bank 2012, Schuhbauer and Sumaila 2016). Its decentralized, diverse and diffuse nature makes it difficult to give a general picture of SSIF and to measure its impact. As a result, the inland fishery sector, whose production is mainly based on small-scale activities, is often dismissed as "*backward, informal and marginal*" (Welcomme et al. 2010, p. 2888). This neglect is fueled by several interrelations, which are often seen one-sided or simplified: First, geographical isolation of fishfolks, mostly living in marginal or remote areas with poor infrastructure, is usually seen as an impediment for development (Béné and Friend 2009). Second, catches from small-scale fisheries often serve domestic consumption or enter the market through informal ways. Therefore, contribution to national economies is largely underestimated and small-scale fishery is often seen to offer little potential for development although more than half of the catch in developing countries is caught by the small-scale sector (Béné and Friend 2009, World Bank 2012). Third, the development of water and water-related resources, like dams for hydropower is commonly considered contrary to the aspirations and needs of fishermen to their social and ecological environment (Sneddon et al. 2002, Friend et al. 2009). Forth, capture fisheries are largely seen as being doomed to decline due to their open access nature facing pressure from population growth, land use changes, infrastructure development and environmental changes (Friend et al. 2009) leading inevitably to 'Malthusian overfishing' (Pauly 1990) and what *Hardin (1968*) called the 'Tragedy of the Commons'. Based on its open access, fishery is often reduced to a "*last resort activity*" for poor people (Béné 2003, p. 955) and fishermen are referred to as the "*the poorest of the poor*" (Béné 2003, p. 951), since the use of common property is said to lead inevitably to a low level of resources and low income (Béné 2003). However, this one-sided perspective ignores the fact that fishermen are not necessarily poor because they are fishermen, but they are fishermen because they are poor (e. g. landless). Fishery, therefore should be also regarded as a 'safety net' and its open access nature, though it does not hold true for all SSF (see Béné 2003), considered positive (Béné et al. 2010). In consequence of common simplistic and reductionist conclusions, that underestimate its potential, inland fisheries often loose out to other sectors and interests (Lynch et al. 2016). Besides the political marginalization, this becomes apparent through an "*inadequate financial, institutional, and scientific support for small-scale fisheries*" and has "*further obscured evidence about the contribution of small-scale fishing communities to conservation,* […] *poverty alleviation, social well-being and resilience, and cultural heritage*" as Chuenpagdee (2012) summarized (p. 22).

Thus, little is known about the drivers of resource exploitation and adaptation strategies of local small-scale inland fishermen to environmental and demographic changes. So far, changes in fisheries have been studied mainly for marine ecosystems (Allan et al. 2005, Chuenpagdee 2012, Sievanen 2014). Understanding the larger economic, ecological, political and social impacts local small-scale fishermen are coping with as well as their vulnerability and perception of change can clarify weaknesses, gaps and challenges in the current fishery management and help decision makers, including fishermen themselves, to develop locally and regionally appropriate adaptation strategies.

This study analyses the current challenges small-scale fishers are coping with as well as their vulnerability to and perception of change. We will answer the following questions: Which changes do small-scale inland fishermen feel exposed to? What are the drivers of change? How do fishermen adapt to those changes and what are the further implications?

Using the SSIF at Lake Alaotra, Madagascar, as an example, we analyzed social, environmental and economic changes and respective consequences that may similarly affect small-scale fishers in rural regions in tropical countries all over the world.

5.2. Materials and methods

5.2.1. Ethics statement

Field work permits were issued by the Madagascar's Department of Environment, Ecology and Forest. Fishers were questioned as available and willing to participate and were informed that their identities and responses would not be shared with anyone. Ethics approval for the study was granted by the Research Ethics Committee of the University of Hildesheim.

5.2.2. Study site

Lake Alaotra in northeast Madagascar (E048° 26', S1 7° 31') is the country's largest freshwater lake and base for the most important inland fishery (Wallace et al. 2015). The shallow lake comprises 20.000 ha of open water body and reaches a maximum depth of 4 m. It is surrounded by 23.000 ha of freshwater marshes and 120.000 ha of rice fields (Pidgeon, 1996; Ratsimbazafy et al., 2013) (Figure 5.1.). The region is characterized by a warm rainy season (November to March) with precipitations (900 to 1,250 mm on average, with a maximum of 250 mm in January) rising the lake water level, and a cold dry season (April to October). The annual mean temperature is 20.6 °C and ranges from 11 °C in July to 28°C in January (Ferry et al. 2009). The overall economic productivity of the region lifts daily income (2.5 USD to 5 USD) well above the national average (78% of the Malagasy population have a daily income below the poverty line of 1.90 US $) and causes strong immigration. Main sources of income are SSIF and rice cultivation (UNDP 2016, Rakotoarisoa 2018).

The wetland complex is internationally recognized as a Ramsar site since 2003 and as a new protected area (Nouvelle Aire Protégée, NAP) by the government of Madagascar since 2007 (Ratsimbazafy et al. 2013). A poor enforcement and low compliance however, has led to the fact that the Lake Alaotra wetland complex is widely regarded as a ‘paper park’ (Razanadrakoto and Rafaliarison 2005, Wallace 2012).

5.2.3. Lake Alaotran fishery

Today, the five predominant fish species in catches at Lake Alaotra are all introduced: two species of tilapia (Nile tilapia *Oreochromis niloticus niloticus*, redbreast tilapia Tilapia rendalli and various hybrids), blotched snakehead (*Channa maculata*), common carp (*Cyprinus carpio carpio*) and goldfish (*Carassius auratus auratus*). Other introduced species found in recent catches are the eastern mosquitofish *(Gambusia holbrooki*), Black bass (*Micropterus salmoides*) and the Mozambique tilapia (*Oreochromis mossambicus*). Fish species native to Lake Alaotra occurring in catches, are the Indonesian short-finned eel (*Anguilla bicolor bicolor*), African longfin eel (*Anguilla mossambica*) and the locally endemic Madagascar rainbowfish (*Rheocles alaotrensis*) (Razanadrakoto and Rafaliarison 2005, Wallace 2012).

The fishery management of Lake Alaotra is enforced through the Fishery Service (*Service Régional de la Pêche et des Ressources Halieutiques*), based in Ambatondrazaka. Another authority, the Federation of Fishers (*Fédération des Pêcheurs*) is supposed to represent the local fishermen and to implement, monitor and develop fishery regulations directly on-site. However, the Federation is suffering from a lack of confidence by locals, due to few interactions with local fishers and a lack of commitment in management (Wallace 2012). Since 1998 fisheries at Lake Alaotra are regulated by gear restrictions and minimum fish size limits. A temporal fishing closure (15 November to 15 January) and spatial fishing closures (fishing is prohibited in no-take zones near the lake edge and strict conservation zones in the center of the marshes), implemented in 2001 and 2006, respectively, aimed to increase effectiveness of management interventions. The two-month fishery closure aims to allow recovery of the fish stocks while no-take zones intend to permanently protect fish spawning sites (Andrianandrasana et al. 2005, Razanadrakoto and Rafaliarison 2005, Wallace 2012). However, these restrictions are not very effective as other protein resources are rare and many fishers have to fish illegally to survive.

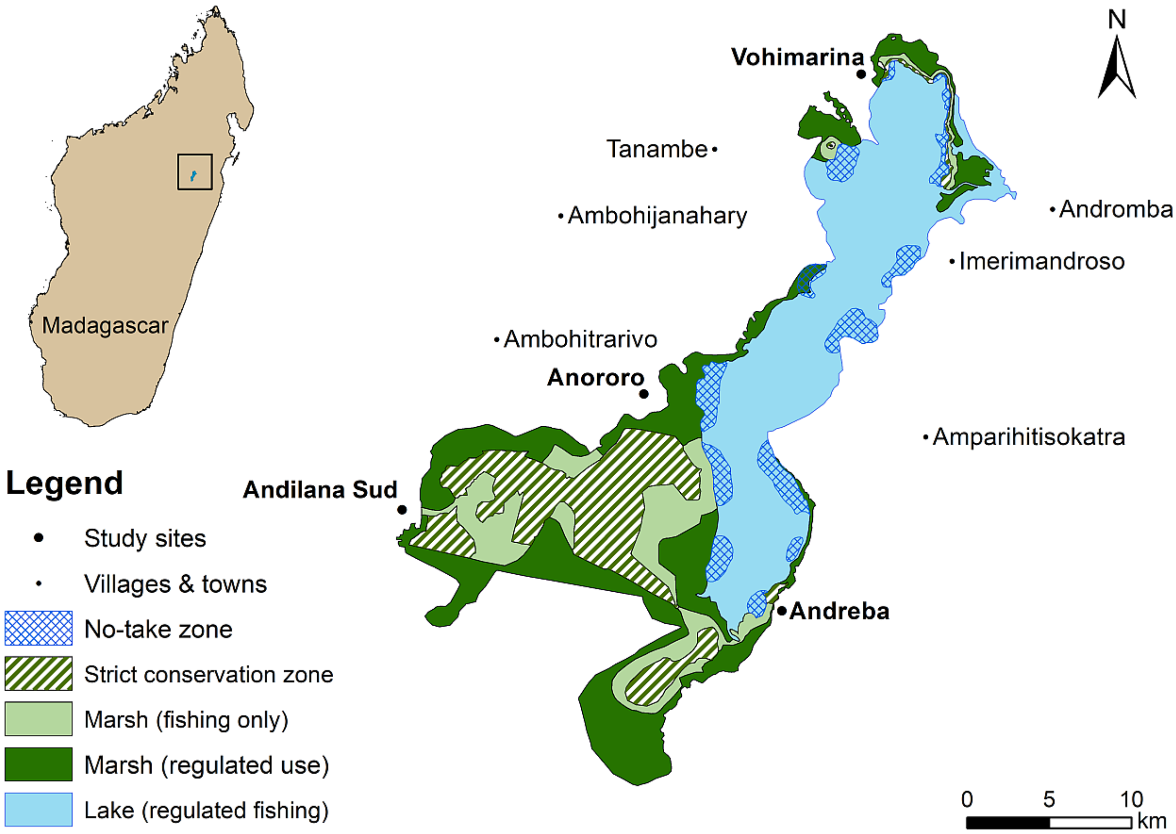

Figure 5.1. Map of Lake Alaotra and its wetland management zonation. Fishing activity is prohibited in strict conservation zones in the center of the marshes and in no-take zones around the lake-edge.

Regional changes and threats: The Lake Alaotra region has undergone significant changes in the past. The human population has increased fivefold during the last 50 years to currently more than half a million people (Pidgeon 1996, Lammers et al. 2015). The drastic population growth had detrimental effects on the entire ecosystem: The low social resilience of the rural population due to high dependency on natural resources entail high human demands on freshwater resources and agricultural land and has resulted in overfishing, marsh burning and subsequent conversion into rice fields (cultivation of '*vary jebo*' during the dry season) and wetland fragmentation. Further, pollution, introduced fish and plant species have altered the freshwater species diversity and composition. Transformation of water bodies and streams for agricultural irrigation as increasing sedimentation have already reduced the lake to 20–30% of its original size (Bakoariniaina et al. 2006, Lammers et al. 2015). Overfishing and environmental degradation have resulted in declining fish catches and decreased crop production of approximately 40% during the last years and led to additional pressure on the remaining natural resources (Pidgeon 1996, Bakoariniaina et al. 2006).

Data collection: Fish surveys were conducted in 2013 and 2014 to measure fish catches regarding catch weight (g), number of caught fishes (n), fish species (or genus in case of tilapia and eel) and size of caught fishes (cm). Fishes were assigned to three size categories (A = < 13cm, referring to the minimum permissible length of Tilapia in catches; B = 13–20cm; C = > 20cm). A total of 859 catches were recorded at different times of the year (March to April 2013, January, June, September to October 2014) at four sites: Andreba, Anororo, Vohimarina and Andilana Sud (Figure 5.1.). Locations encompass a range of community types, from little villages to bigger communes (Inhabitants: Anororo, 8000; Andreba, 5000; Vohimarina, 500; Andilana Sud, 3900; pers. comm. with village chiefs 2016, Wallace et al. 2016).

To gain a better understanding about fishers' attitudes and behaviors, data of fish catches were supplemented with information about fishermen's everyday working life, problems and perceptions through structured interviews (see Appendix 13.). Interviews, consisting of 39 closed and 2 open questions (indicated with Q and the respective number of the question in the interview e.g. Q1), were conducted in March 2017. 117 fishermen were interviewed, 28 to 30 in each of the four sites. Interviews were conducted by a local Malagasy research assistant and took place at the local harbor. The categories for closed questions were developed based on the respondents of a preliminary study conducted in Andreba with 44 fishermen. Preselected categories minimized the required time for conducting interviews in order to increase fishers' probability and willingness of participation. Interviews were 30 minutes in duration and addressed issues about their work as a fisherman (e.g. gear specification, daily working routine, income and livelihood diversification) as well as their perception about changes, problems and the future of Lake Alaotra fisheries.

In order to draw a general picture of the Lake Alaotran fishery since its expansion in the middle of the 20th century, additional data about yearly fish production and number of fishermen were collected from literature and from the regional directorate of fish resources and fisheries (*Direction Régionale des Ressources Halieutiques et de la Pêche*) in 2017.

Data analyses: Data from fish catches (n = 859) were analyzed jointly for all sites and time periods. Overall 117 interviews were conducted and later used for data analyses. Interviewed fishermen (n = 117) at Lake Alaotra were all male, on average 40 years old (age 17 to 71 years) and had 17 years (1 to 51 years) of experience in their work as a fisherman (Q1,2,4). Interviews contain questions generating qualitative and quantitative data. Qualitative data was analyzed by using qualitative content analysis (Mayring 2016).

The average intercoder reliability of 99% (n = 2) was calculated following Holsti (1969) and ranged between 97% to 100%. Coding discrepancies were resolved through discussion before analysis continued. Literal interview excerpts are indicated by an interview identifier made up of the sites name and consecutive interview number (e.g. VF15). As multiple answers were allowed, sum of response percentages can exceed 100%. Given percentages are calculated for the 117 respondents. In case of subgroups exact sample size are shown in brackets. All results from interviews can be found in Appendix 14.

Income data obtained from structured interviews are given in US Dollar (USD) using the exchange rate of March 2017 (MGA/USD = 3,177), the time period when interviews took place.

Since data from fish surveys and interviews do not follow normal distribution, average values are given as median (range).

5.3. Results

Evolution of the Alaotran fishery: The Lake Alaotran fishery shows since its expansion in the mid of the 20th century an opposing development: while fish catches (in tonnes) fall sharply since the 1960s, the fishery sector (number of fishermen) is growing continuously, especially since 1975 (Figure 5.2.). The maximum yield of the Alaotran fishery was already reached in the 1960s with 4000 tonnes of fish per year allocated to around 1000 fishermen. Currently fish catch has dropped to less than 1000 tonnes per year while the number of fishermen has increased more than tenfold up to 12000 (DRPRH 2016, unpublished data). The high pressure on the Alaotran fish stocks is reflected by our data from fish surveys: 80% of the caught fishes (n = 859 fish catches, n = 57077 individuals) had a length of less than 13 cm (Category A). Only a small proportion of 3% reached the size category C with a length of more than 20 cm. The species composition of fish catches was poor and consisted of 7 species or rather genera: *Tilapia* spp., *Channa maculata*, *Cyprinus carpio carpio*, *Micropterus salmoides*, *Carassius auratus*, *Anguilla* spp., *Awaous aeneofuscus*. Catches are dominated (n = proportion by number of individuals, w = proportion by catch weight) by Tilapia species (n = 94%, w = 82%) and, even though to a smaller extend, the invasive snakehead Channa maculata (n = 3%, w = 9%), while all other species account only for a small proportion (n = 1%, w ≤ 3%) of the catches.

Figure 5.2. Annual fish catches and number of fishermen in the Alaotra basin during past 60 years. Solid line = annual fish catches in tonnes; dotted line = number of fishermen. Sources: (Pidgeon 1996, Moreau 1979/80, DRPRH 2016, unpublished data).

The high popularity of fishing: Though interviewees state that „*The fishes were more numerous and easier to catch before*" (VF3) and hence noticed that fishery has become less profitable (16%), the possibility to catch fish all year round (44%) and the remaining big and/or valuable fishes (27%) give rise to the recent popularity of fishing (Q33). The daily generated income (Q14) by fishing of 2.5 USD (n = 109; ranging from 0.38 to 12.6 USD) still lies well above the national average of 1.1 USD (World Bank, 2017). However, merely 17% (Q15) of the respondents are full-time fishermen, earning their livelihood exclusively by fishing, whereas the majority (83%) work part-time as fishermen (including seasonal, occasional and part-time fishermen). Daily generated income (Q14) by fishing, however, did not differ between full-time and part-time fishermen. Further results reflect that the combinability, low entry barriers and low opportunity costs of fishery are key factors for its popularity: (i) a large part of the interviewees fish for seven days a week (rainy season: 55%, dry season: 60%, Q10 1,2) but hours spend for daily fishing trips (Q9) are not more than 3:42 h on average (see Appendix 15.). (ii) The most commonly used method are traps (60%; Q6) which are usually placed and checked during night and early morning hours and therefore allow for other occupations during daytime. (iii) Besides the methods' easiness (64%, e.g. easy usage and maintenance, non-arduous work) and economic advantages (20%, e.g. high catch rates) its combinability with an additional occupation was a key reason for method selection (12%; Q7): „*I can still do another job after checking the vovo* [fish trap]" (VF15). (iv) Likewise, practical and economic reasons were main determinants of occupational choice (Q5) for around half of the fishermen rather than family tradition (25%) and personal aspiration (27%): 'Easiness' (20%) was mainly specified as low barriers regarding required education (9%; „*You don't need to be educated*" , AGF1; „*I failed at school*", VF24), low special effort (6%; „*I live next to the harbor. That's why I work in the water*", ASF8) as well as little financial investments needed (2%). Economic factors aim at securing livelihoods (need of additional job, 6%; lacking alternatives, 8%; poverty, 2%; year-round source of income, 13%).

Perceived problems and future perspectives of the SSIF: In fact, there was a clear awareness of the decline in fish catches as it is perceived by 85% of the respondents as the main change in fisheries (Q34) and 63% of the fishermen (Q31) said to be personally affected. Other problems the Alaotran fishery sector has to contend with (Q30) are social conflicts and criminal behavior brought up by 85% of the respondents (Q30). Generally, conflicts are specified as stealing of fishing gear or fishes (24% and 14%, respectively) and disturbing or destroying fishing gear (15%). Other problems were lacking equipment, smaller fishes and low water levels.

Questioning about the barriers for becoming a fisherman (Q23) further disclosed a poor motivation to fish if someone has enough money, fields or work on the land (25%) or other jobs (4%), since many respondents here misunderstood the question. Interviewees argued that: „*People that have a lot of fields do not have to work in the water*" (ASF4) or that „*They have enough work on the land*" (ANF29). Direct barriers mentioned were money for fishing gear (41%), boats (8%), learning to fish (13%) and the fisherman's hard and frightening work (7%; „*They fear the water*", AGF5; „*Fishing is a hard work*", ASF24).

The awareness of aforementioned challenges was reflected by comments on fishery's future perspectives (Q41) which were generally seen negatively (85%). Only 8% of fishers still believed in the continuity of the Alaotran fishery. Another group (11 %) offered a disillusioned view with a more or less fatalistic attitude towards fishery, expressed by statements like „*There is no change anymore so we work on land and in the water, even if it is difficult*" (ASF17), or attributed to a perceived uncertainty or lacking alternatives and experiences outside the fishery sector: „*The future is unknown but I will go on with fishing because I am used to it*" (VF27). Fishers negative perspective became apparent by their desperation and the hopelessness they ascribed to fishery: „*I do not have any hope regarding the livelihood here and I am still* *searching for solution until now*" (VF2), whereas a quarter of them specified: „*There is no hope anymore for fishing so I have to find other jobs*" (VF5).

Thus, it is not surprising that the clear majority (71%, n = 83; Q40) disliked the idea of their sons becoming a fisher like themselves justified by the livelihood insecurity nowadays attributed to fishing (64%), a high burden of work (18%) and the aspiration that their sons might get a 'better job' (18%). However, still more than one quarter (28%, n = 33) are wishing their sons to become a fisher, mainly because of adhering to family tradition (52%) and having little other assets (52%): learning to fish was seen as a solution for school failure (18%), shortfalls due to poverty (18%) and as an alternative to unemployment or even criminality (15%) by generating at least a small income. Arguing that „*Like that he can still work but not steal in case he will not find other jobs*" (VF22) and emphasizing that „*Agriculture is now bad so he has to fish since he lives next to the water*" (VF15) highlights fishery's function as a safety net for rural poor.

The expanding fishery sector – fishing as a rural adaption strategy: People at Lake Alaotra increasingly enter the fishery sector since decades. One driver is certainly the daily generated income by fishing (2.5 USD) which is at the lower end for the Alaotra region per capita income of 2.5–5 USD (Rakotoarisoa, 2018) but lies still above the national average. However, investment capacity (Q14) of fishers remains low since solely 21% of the interviewees stated to have enough income to invest in their business and hereby to improve their economic situation. Half of the interviewees (55%) said to be able to cope with financial bottlenecks, while for one quarter (25%) income is just enough to buy food but not for building up any reserves.

Fishery was mostly combined with former activities to provide additional income (58%, n = 58; Q15B), mainly to complement agriculture (85%). Livelihood diversification was mainly based on economic reasons like lower yields, too few fields to feed the family (including having now to share fields with children), decreased income or general livelihood insecurity: „*Life is becoming difficult and the yields are decreasing*" (AGF29). Statements like „*There are not enough fields to use*" (ANF13) and „*I do not have enough field*" (VF16) pointed out the general lack of agricultural land, which hinders interviewees to expand agriculture. Full-time fishers (17%, n = 20; Q15A) largely lamented, that fishery does not support their livelihoods any more (85%) but a lack of fields, equipment or education hinders them to practice another occupation. Likewise, former full-time fishermen (25%, n = 29; Q15C) started to diversify their livelihood, notably during the last decade (70%). Reasons were declining catches (28%), decreasing income (17%) and livelihood insecurity (14%).

Regional changes – drivers of livelihood diversification? 97% (n = 113; Q38 1,2) of the respondents noticed changes in the Alaotra region, mainly referring to smaller catches (57%), yield reduction in agriculture (12%) and climate variability related topics (16%). For the latter issue interviewees explain, that "*The year is disturbed*" (ASF29), „*The rain is delayed*" (VF14) and that „*A lack of rain decreases the water level in the Alaotra*" (ANF6). Some of them further noted that "*it makes the rice planting late*" (ANF18) and "*delays the fishing and the agriculture and* [makes] *the village* […] *insecure*" (ANF23) as well, that „*The income is bad because of the low water level*" (ANF24). Increase of social conflicts (9%) and criminal behavior (8%) were additional changes observed. Interviewees reported, that „*People in the society are jealous of each other and have conflicts with each other*" (ASF11), that „*Due to the difficulties of life the society is destroyed*" (ASF30) and that „*The insecurity increased a lot in the Alaotra*" (VF10). The few remarks referring to positive changes (5%) were largely premised on better yields or catches due to unsustainable or illegal practices, either fishing during the fishing closure or the planting of '*vary jebo*'. Reasons for change (Q38 3) for the worse (climate variations, environmental degradation, livelihood insecurity, diminishing catches and harvests, use of illegal methods, destruction of small fish, criminal behavior, jealousy, weak government) give evidence for a strong nexus between environmental, societal, political, and economic dimensions and the fishery sector. Local societal linkages seem strongly under stress as one interviewee observed: „*Even the educated people are fishing because they don't find other jobs*" (AGF21).

Asked about trends in the rainy season (Q36 1,2,3), almost all interviewees observed its delay. 98% (n = 112 mentioned that this has a direct negative impact on their livelihood, notably fishery (65%, as delayed activities/income and fewer fishes due to a later increase and overall lower water level) and agriculture (32%, referring to delayed activities and poor or delayed yields). Asking fishermen about the start of the rainy season in their childhood (Q35) revealed, that the older they were, the earlier the rainy season started according to their memories. 96% of fishermen dating their childhood more than 40 years ago (40–59 years, n = 26) stated that the rain season had started before December in their childhood, while the same applies for 72% of those dating their childhood over 20 years ago (20–39 years, n = 60) and for only 42% of the younger interviewees, dating their childhood within the last two decades (4–19 years ago, n =31).

5.4. Discussion

Small-scale fishery has served for a long time as a livelihood opportunity with low entry barriers in rural areas next to water bodies, and hence as a safety net especially for the rural poor. However, nowadays this 'net' seems strained to its breaking point.

The Lake Alaotran fishery – symptomatic for imminent changes in the tropics and subtropics? At Lake Alaotra the number of people engaged in inland fishery is increasing sharply since the mid of the 20th century. First data from 1954 register no more than 100 fishermen since fishery does not have a long tradition at Lake Alaotra (Moreau 1979/80). This number has risen dramatically during the last 60 years to a total of app. 12000 fishermen today. The Lake Alaotran fishery reflects the rapid growth of the inland fishery sector in developing countries over the last century, triggered by population growth and limited employment possibilities in rural areas (FAO 2002, Allan et al. 2005, FAO 2016). In the recent past (1990–2012), employment in fishery has worldwide grown faster than the world's population, and faster than employment in traditional agriculture (FAO 2014). Our results show, that the vast majority of the fishers at Lake Alaotra are part-time fishers (83%), earning their livelihood through various occupations. This implies that the National census method underestimates the number of fishermen, since fishers that fish only temporarily may not call themselves 'fishermen' (Sultana et al. 2003, Mills et al. 2011, Bartley et al. 2015, FAO 2016). The group of part-time fishers is especially high in developing countries and inland fisheries since it represents a crucial strategy for livelihood diversification (FAO 1999, Smith et al. 2005, FAO 2010, Béné and Friend 2011, Sievanen 2014). In our study half of all fishermen earned their living by agriculture before they started to fish. The decision to fish is based on economic drivers like decreasing yield or income, a lack of equipment for agriculture or insufficient land and general livelihood insecurity. These drivers are globally symptomatic for the tropics and subtropics, where high demographic growth and an increasingly irregular distribution of precipitation are resulting in soil degradation, landlessness and finally crop shortfalls, reduced yield potential and the loss of useable land (Sonwa et al. 2016, FAO et al. 2017, Webb et al. 2017). In the Inland Niger Delta, fishery has served as a safety net for farmers since droughts in the 70s and 80s have led to decreased harvests (Sarch and Allison 2000). A similar case has been observed for the Lake Mweru and the Luapula River fishery, where droughts are likely to increase the influx into the fishery sector from agriculture (Van Zwieten et al. 2003). So, Lake Alaotra seems to reflect an alarming trend, which can be seen in many regions of the world already and may affect a larger number in the near future.

The immanent need for livelihood diversification – people's adaption to change: Altered conditions for agriculture and lacking alternative sources of income are the main reasons for the expansion of the inland fishery sector at Lake Alaotra. Supplying one third of the countries rice production, the Alaotra region became the so-called 'rice granary' of Madagascar and therefore a favored region for migration (Andrianirina 2013, Ratsimbazafy et al. 2013). Today, the rising need for agricultural land diminishes the remaining wetlands due to their conversion into rice fields while intensification of rainfed agriculture has led to soil fertility loss and erosion. Low investment capacities, fluctuating prices and high intra- and inter-annual changes of the rainy season expose local farmers to additional risks. As an overall result of those interrelated changes, yields in crop production have declined or at least stagnated (Van Zwieten et al. 2003, Andrianirina 2013, Bruelle 2014, Bruelle et al. 2014). On an individual level the proportion of agricultural land per person (or rather family) is further reduced because fields are shared within the next generation/with children. Decreasing yields and the lack of agricultural land were the main reasons for a large part of fishermen to start fishing on a part-time basis. Interlinked reasons (e.g. decreasing income, lacking equipment and livelihood insecurity) moreover show, that the higher population density implies a generally higher competition for employment opportunities. Welcomme (2001) concludes that part-time fishers, earning income from other sources (e.g. labor, transport) will invest less time in fishery as soon as it is no more profitable for them. However, as the author continues, part-time fishers, whose alternative sources of income are on a seasonal basis (e.g. seasonal crop cultivation), will continue to fish during downtimes even when catches are low. For Lake Alaotra, cultivation downtimes determinate the life of the local population as agriculture, is dictated by the crop seasons (Ducrot and Capillon 2004). During those downtimes fishing is often the only alternative source of income. We assume that the entry into fishery at Lake Alaotra will be increasingly guided by economic reasons and its easy practicability rather than tradition and personal preference: at least half of the interviewees started to fish because of livelihood insecurity, the opportunity of cash income on a daily basis and the low entry barriers of fishery (no need of education and low or no need of financial investments). Since our study disclosed that more than two third of the interviewees wish their children/sons to pursue a different profession, the lack of alternatives is one important reason for the sector's continuing popularity. As Morand et al. (2005) confirm for West Africa, the increased need for cash, the lack of alternative sources of income and consistently increasing demand for fish are the main reasons encouraging people to take up fishery. They emphasize the increasing shortage of farmland, the unpredictable nature and low profitability of rainfed agriculture under increasing variability of the climate, the low work possibilities of rural people in town due to educational deficits and the insecure livelihoods of people in the informal sector. Considering the trend of a progressive shortening of the rainy season at Lake Alaotra (Bruelle et al. 2017) and of a ‘shifting baseline’ pattern regarding the onset of the rainy season in our study, economic shortfalls in other sectors will accelerate the influx in inland fishery as it is seen to be one of the major indirect impacts of climate change on fishery (Daw et al. 2009). The impact of such a scenario on the local population of fishers is nevertheless poorly analyzed (Badjeck et al. 2010).

Constraints and consequences of development – from a safety net to a poverty trap: The alternating labor transfer between the agricultural and fishery sector is common in resource poor rural areas close to water bodies (Cochrane et al. 2009, Badjeck et al. 2010, Welcomme et al. 2010). However, at Lake Alaotra a scenario becomes apparent where both sectors seem to have reached their upper limit of expansion and where fishery might lose its crucial ‘safety net’ and ‘labor buffer’ function as it is defined by Béné et al. (2010). Those mechanisms are “*crucial from a social and economic point of view, especially in remote areas where alternative employment may be scarce and social-security programmes either minimal or nonexistent*” (ibid, p. 349), and they have prevented people from economic crisis, political conflicts, natural catastrophes worldwide and given a livelihood to the rural poor (e.g. job losses, Jul-Larsen 2003; civil war, Béné et al. 2010; weather events, Mahon 2002; agricultural failure, Conway et al. 2005; food insecurity, Meusch et al. 2003). At Lake Alaotra, agriculture and fishery are suffering substantial losses simultaneously, driving farmers to engage in fishing and vice versa. Lacking alternatives hinder them to exit and instead trap them in declining sectors. A point of no return is indicated by a raising number of fishermen even in the light of the fact of (i) fishers’ overall negative perspective on the future of fishery (ii) the disliked/unpopular idea of their sons becoming fishermen following family tradition and (ii) the variety of challenges fishers are facing (e.g. declining catches, livelihood insecurity, high workload, criminal and adversarial behavior, low water levels). The fact, that (iv) current full-time fisher are willing to exit fishery but hampered due to lacking assets (fields, money for equipment) supports the hypothesis about fishery reaching a point of no return and becoming a trap rather than a safety net.

Current development manifests in a sustained annual catch decline (reduced to less than one quarter over the past 50 years) as well as changes in species composition (further confirmed by Moreau 1979/80, Collart et al. 1980, Pidgeon 1996). Lower reproduction rates, since individuals are largely caught before reaching maturity (Dadzie and Aloo 1990, Lorenzoni et al. 2007, Froese and Pauly 2017), genetic deterioration and trophic composition changes are most likely involved. Additional interlinked effects and cross-sectoral responses observed to come along with overfishing are conflicts and competition over livelihood opportunities, fishing places and gear, decreasing income and increasing poverty. As observed in other regions (Okpara et al. 2016, FAO 2017), local people balance livelihood insecurity by usage of destructive fishing methods, the unsustainable expansion of agriculture into the marshes, leading to destruction of spawning sites, and criminal behavior (e.g. stealing). According to Pomeroy et al. (2007), who documented such a negative feedback cycle in Indonesia, it occurs especially when rapid population growth, fewer livelihood opportunities and access to land are intensifying fishing pressure and can lead to fish stock depletion or collapse and food insecurity. Having tremendous impacts on human behavior, social environment as well as ecosystem properties, such an undesired development is leading to an overall increased vulnerability of communities (FAO 2016).

For longterm sustainable exploitation of stocks fishers' willingness and ability to exit fishery will play a crucial role. Following Daw et al. (2012), entry to and exit from fisheries has been observed to be often not guided by profitability as many models indicate. The local and individual context (e.g. socio-economic factors, age, education, occupational attachment and identity, type of fishing) is assumed to be significant for exiting and therefore may force fishers to stay in fishery although profitability is low (ibid). Smith et al. (2005) and Martin et al. (2013) analyzed, that fishing, used as a strategy to spread risks, is often maintained alongside other occupations to keep economic mobility, regardless of opportunity costs. Whereas Cinner et al. (2009) and Daw et al. (2012) predict that the availability of alternative livelihood options increases opportunity costs of and enhance displacement from fisheries, implying that regions lacking alternative livelihoods, as the Alaotra region, are more affected by overfishing. The prevalent use of passive fishing methods during nighttime (making fishing combinable with daytime employment) and low-cost gear (traps) indicates the already low investment capacities (either time and/or money) of the Alaotran households (cf. Smith et al. 2005). Decreasing productivity in fishery and agriculture will successively lower investment capacities further and make displacement in other sectors increasingly unlikely.

Future development considerations: Our findings confirm, that the safety net function of SSIF is crucial for rural people's livelihood security and a sound social environment. Secondly, our study indicates that current trends of population growth, land use change and climate variability in developing countries may strain this safety net to its breaking point: increasing human pressure may exceed fish stock regeneration capacity and let people 'fall' into a poverty trap (Cinner et al. 2009). Corresponding to literature about poverty traps (Barrett et al. 2006, Béné et al. 2010), Alaotran full-time fishers were largely excluded from alternative livelihood strategies with higher returns while lacking alternatives at the same time force other people to enter fisheries despite its declining productivity. Although a bunch of literature has recently emerged about the importance of SSF' welfare functions and its policy implications (Barrett et al. 2006, Cinner et al. 2009, Béné et al. 2010, Barrett and Carter 2013), policy objectives mainly adhere to mainstream wealth-based models focusing on a maximizing economic rent and gross domestic product contribution while explaining poverty by the Malthusian logic (Pauly 1990, Béné et al. 2010). As wealth-based model aligned policy focuses on resource access control and fishing effort reduction in order to increase fisheries overall productivity (Béné et al. 2010) it bears the risk of excluding precisely those rural poor, whose livelihoods depend on it. The case of the Alaotran fishery highlights that a more profound analysis of people's livelihoods can identify ongoing livelihood dynamics and disclose possible poverty trap mechanisms. Awareness of the dichotomy between the welfare and wealth-based model underlying policy and the understanding of fisheries current function are essential for local management orientation and the understanding of management failures: (i) spatial fishing closures combined with gear restrictions can be more effective than temporal fishing closures if fishers are highly dependent on daily cash income (cf. Daw et al. 2012, McClanahan et al. 2005, Wallace 2012). (ii) Gear exchanges for fishers practicing illegal and destructive methods can encourage compliance with gear restrictions and reduce social tension (Cinner 2010). (iii) Temporal fishing closures should consider fish species reproductive cycles and local livelihood adaptions to intra-annual cycles. The current fishing closure at Lake Alaotra is too late to effectively protect spawning fishes (Wallace et al. 2015). The closure aims to encompass the rice-cultivation period with its high employment opportunities outside fisheries but Ducrot and Capillon (2004) have shown that time of crop establishment defines the most critical time for farmers. During this time when cash is scarce and hungry gaps can hardly be avoided, local populations rely most on additional daily income by fishing. (iv) Management should foster dynamic (temporal) or mobile (spatial) fishing closures for a more equal distribution of benefits and costs (Wallace et al. 2015), facilitate a flexible reaction on the inter-annual changes and shifts by climate variability and consider spatial and temporal trade-offs between land use and fishery, especially in regard of current precipitation patterns (cf. Cochrane et al. 2009). (v) Economic mobility is required to overcome shocks and to adapt to change. Income decline can cause stochastic (often temporary) poverty while the loss of assets leads to structural (often persistent) poverty, where economic mobility is lost and people may be caught in a poverty trap (Carter and Barrett 2006). Management interventions should therefore also focus on building and protecting fishers' assets (Barrett et al. 2006, Carter and Barrett 2006, Cinner et al. 2009, Béné et al. 2010).

Our study shows that in the near future, SSIF ability to provide livelihoods will become increasingly important, particularly in rural areas, where infrastructure is poor and livelihood options are scarce. Policy makers and international agencies are now obligated to fathom the local value of fisheries' welfare function and decide about implications for future fishery management.

5.5. Acknowledgement

We thank all participants of this study and particularly Lala Nomenjanahary Elysé and Bernard Aimé Rajaonarivelo for their assistance with field work. We also thank the community of Andreba, Andilana Sud, Anororo and Vohimarina for their cooperation and hospitality as well as Durrell Wildlife Conservation Trust in Ambatondrazaka, the Service Régional de la Pêche et des Ressources Halieutiques and the Ministère de l' Environnement, de l' Ecologie et des Forêts for supporting this work. The research was supported by the Bauer-Stiftung (Deutsches Stiftungszentrum).

5.6. References

Allan, J. D., Abell, R., Hogan, Z. E. B., Revenga, C., Taylor, B. W. et al. 2005. Overfishing of inland waters. *BioScience* 55, 12: 1041–1051.

Andrianandrasana, H. T., Randriamahefasoa, J., Durbin, J., Lewis, R. E. and Ratsimbazafy, J. H. 2005). Participatory ecological monitoring of the Alaotra wetlands in Madagascar. Biodiversity and Conservation, 14, 11: 2757–2774.

Andrianirina N. 2013. L'agricuclture pour le développement : pertinence et limites à l'échelle des ménages ruraux. Une approche dynamique comparative pour trois régions de Madagascar [dissertation]. *École doctorale Economie Gestion, Centre international d'études supérieures en sciences agronomiques*, Montpellier, France. 170 pp.

Badjeck, M. C., Allison, E. H., Halls, A. S. and Dulvy, N. K. 2010. Impacts of climate variability and change on fishery-based livelihoods. *Marine policy* 34, 3: 375–383.

Bakoariniaina, L. N., Kusky, T. and Raharimahefa, T. 2006. Disappearing Lake Alaotra: monitoring catastrophic erosion, waterway silting, and land degradation hazards in Madagascar using Landsat imagery. *Journal of African Earth Sciences* 44, 2: 241–252.

Barrett, Ch. B., Marenya, P. P., Mcpeak, J., Minten, B., Murithi, F. et al. 2006. Welfare dynamics in rural Kenya and Madagascar. *Journal of Development Studies* 42, 2: 248–277.

Barrett, Ch. B. and Carter, M. R. 2013. The economics of persistent poverty and poverty traps: empirical and policy implications. *Journal of Development Studies* 49, 7: 976–990.

Bartley, D. M., De Graaf, G. J., Valbo-Jørgensen, J. and Marmulla, G. 2015. Inland capture fisheries: status and data issues. *Fisheries Management and Ecology* 22, 1: 71–77.

Béné, C. 2003. When fishery rhymes with poverty: a first step beyond the old paradigm on poverty in small-scale fisheries. *World development* 31, 6: 949–975.

Béné, C. and Friend, R. M. 2009. Water, poverty and inland fisheries: lessons from Africa and Asia. *Water International* 34, 1: 47–61.

Béné, C. and Friend, R. M. 2011. Poverty in small-scale fisheries. *Progress in Development Studies* 11, 2: 119–144.

Béné, C., Hersoug, B. and Allison, E. H. 2010. Not by rent alone: analysing the pro-poor functions of small-scale fisheries in developing countries. *Development Policy Review* 28, 3: 325–358.

Bruelle, G. 2014. Pertinence de l'agriculture de conservation pour tamponner les aléas climatiques: cas des systémes de culture en riz pluvial au Lac Alaotra, Madagascar [dissertation]. *Université d'Antananarivo, Montpellier SupAgro*. 110 pp.

Bruelle, G., Naudin, K., Scopel, E., Domas, R., Rabeharisoa, L. et al. 2014. Short- to mid-term impact of conservation agriculture on yield variability of upland rice: evidence from farmer's fields in Madagascar. *Experimental Agriculture* 51, 1: 66–84.

Bruelle, G., Affholder, F., Abrell, T., Ripoche, A., Dusserre, J. et al. 2017. Can conservation agriculture improve crop water availability in an erratic tropical climate producing water stress? A simple model applied to upland rice in Madagascar. *Agricultural Water Management* 192, 281–293.

Carter, M. R. and Barrett, C. B. 2006. The economics of poverty traps and persistent poverty: an asset-based approach, *The Journal of Development Studies* 42, 2: 178–199.

Chuenpagdee, R. 2012. Global partnership for small-scale fisheries research: too big to ignore. *SPC Traditional Marine Resource Management and Knowledge Information Bulletin* 29: 22–25.

Cinner, J. E., Daw, T. and McClanahan, T. R. 2009. Socioeconomic factors that affect artisanal fishers' readiness to exit a declining fishery. *Conservation Biology* 23, 1: 124–130.

Cinner, J. E. 2010. Poverty and the use of destructive fishing gear near east African marine protected areas. *Environmental Conservation* 36, 4: 321-326.

Cochrane, K., De Young, C., Soto, D. and Bahri, T. 2009. Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. *Technical Paper. No. 530,* Food and Agriculture Organization of the United Nations (FAO), Fisheries and Aquaculture, Rome. 212 pp.

Collart, A., Rabelahatra, A. and Rasolofo Andriamahaly, L. 1980. Premiers résultats des statistiques des pêches au Lac Alaotra. *Document Technique MAG/76/002*, Ministère du Développement Rural et de la Réforme Agraire, Antananarivo, Madagascar.

Conway, D., Allison, E., Felstead, R. and Goulden, M. 2005. Rainfall variability in East Africa: implications for natural resources management and livelihoods. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences* 363, 1826: 49–54.

Dadzie, S., and Aloo, P. A. 1990. Reproduction of the North American blackbass, *Micropterus salmoides* (Lacepède), in an equatorial lake, Lake Naivasha, Kenya. *Aquaculture Research* 21, 4: 449–458.

Daw, T., Adger, W. N., Brown, K. and Badjeck, M. C. 2009. Climate change and capture fisheries: potential impacts, adaptation and mitigation. In: *Climate change implications for fisheries and aquaculture: overview of current scientific knowledge*. K. Cochrane, C. De Young, D. Soto, and T. Bahri (eds.), pp. 07–150. FAO Fisheries and Aquaculture Technical Paper No. 530, Rome.

Daw, T. M., Cinner, J. E., McClanahan, T. R., Brown, K., Stead, S. M. et al. 2012. To fish or not to fish: factors at multiple scales affecting artisanal fishers' readiness to exit a declining fishery. *PLoS One*,7, 2: e31460.

DRPRH- Direction Régionale des Ressources Halieutiques et de la Pêche 2016. *Statistique production ressources halieutiques*. Ambatondrazaka, unpublished data.

Ducrot, R. and Capillon, A. 2004. A practice analysis to account for adoption of innovations in irrigated rice cropping systems in Lake Alaotra (Madagascar). *Journal of Sustainable Agriculture* 24, 3: 71–96.

FAO 1999. Fishery information, data and statistics unit. Numbers of fishers 1970–1996. *Food and Agriculture Organization of the United Nations, Fishery Information Data and Statistics Unit*, Rome. 131 pp.

FAO 2002. The state of world fisheries and aquaculture. *Food and Agriculture Organization of the United Nations*, Rome. 150 pp.

FAO 2010. The state of world fisheries and aquaculture. *Food and Agriculture Organization of the United Nations*, Rome. 197 pp.

FAO 2014. The state of world fisheries and aquaculture. Opportunities and challenges. *Food and Agriculture Organization of the United Nations*, Rome. 223 pp.

FAO 2015. Voluntary guidelines for securing sustainable small-scale fisheries in the context of food security and poverty eradication. *Food and Agriculture Organization of the United Nations*, Rome. 14 pp.

FAO 2016. The state of world fisheries and aquaculture. Contributing to food security and nutrition for all. *Food and Agriculture Organization of the United Nations*, Rome. 190 pp.

FAO 2017. Status of inland fisheries in Africa, CIFAA/XVII/2017/4. *FAO Fisheries and Aquaculture Department, Committee on inland fisheries and aquaculture of Africa*, Gambia. 12 pp.

FAO, International Fund for Agricultural Development (IFAD), the United Nations Children’s Fund (UNICEF), World Food Programme (WFP), World Health Organization (WHO) 2017. The state of food security and nutrition in the world. Building resilience for peace and food security. *Food and Agriculture Organization of the United Nations*, Rome. 119 pp.

Ferry, L., Mietton, M., Robison, L. and Erismann, J. 2009. Alaotra Lake (Madagascar) – past, present and future. *Zeit fur Geo* 53, 3: 299–318.

Friend, R., Arthur, R. and Keskinen, M. 2009. Songs of the doomed: the continuing neglect of capture fisheries in hydropower development in the Mekong. In: *Contested waterscapes in the Mekong region: hydropower, livelihoods and governance*. F. Molle, T. Foran, and M. Käkönen (eds.), pp. 307–332. Routledge, London.

Froese, R. and Pauly, D. (eds.). 2017. *FishBase.* World wide web electronic publication. Version (02/2018). https://www.fishbase.org. September 6, 2017.

Hardin, G. 1968. The tragedy of the commons. *Science* 162, 3859: 1243–1248.

Holsti, O. R. 1969. *Content analysis for the social sciences and humanities*. Addison-Wesley Publishing Company Inc., Reading. 236 pp.

Jul-Larsen, E. 2003. Analysis of effort dynamics in the Zambian inshore fisheries of Lake Kariba. In: *Management, co-management or no management? Major dilemmas in southern African freshwater fisheries. 2 Case studies*. E. Jul-Larsen, J. Kolding, R. Overå, J. Raakjær Nielsen, and P. A. M. van Zwieten (eds.), pp. 233–252. FAO Fisheries Technical Paper No. 426/2, Rome.

Lam, V.W., Cheung, W.W., Swartz, W. and Sumaila, U. R. 2012. Climate change impacts on fisheries in West Africa: implications for economic, food and nutritional security. *African Journal of Marine Science* 34, 1: 103–117.

Lammers, P. L., Richter, T., Waeber, P. O. and Mantilla-Contreras, J. 2015. Lake Alaotra wetlands: how long can Madagascar's most important rice and fish production region withstand the anthropogenic pressure? *Madagascar Conservation and Development* 10, S3: 116–127.

Lorenzoni, M., Corboli, M., Ghetti, L., Pedicillo, G. and Carosi, A. 2007. Growth and reproduction of the goldfish *Carassius auratus*: a case study from Italy. In: *Biological invaders in inland waters: Profiles, distribution, and threats*. F. Gherardi (ed.), pp. 259–273. Springer, Dordrecht.

Lynch, A. J., Cooke, S. J., Deines, A. M., Bower, S. D., Bunnell, D. B. et al. 2016. The social, economic, and environmental importance of inland fish and fisheries. *Environmental Reviews* 24, 2: 115–121.

Mahon, R. 2002. Adaptation of fisheries and fishing communities to the impacts of climate change in the CARICOM region. Issue paper-draft. Mainstreaming adaptation to climate change (MACC) of the Caribbean Center for Climate Change (CCCC). *Organization of American States*, Washington, DC. 33 pp.

Martin, S. M., Lorenzen, K. and Bunnefeld, N. 2013. Fishing farmers: fishing, livelihood diversification and poverty in rural Laos. *Human Ecology* 41, 5: 737–747.

Mayring, P. 2016. *Einführung in die qualitative Sozialforschung. Eine Anleitung zu qualitativem Denken*. Beltz Verlag, Weinheim. 170 pp.

McClanahan, T. R., Maina, J. and Davies, J. 2005. Perceptions of resource users and managers towards fisheries management options in Kenyan coral reefs. *Fisheries Management and Ecology* 12, 2: 105–112.

Meusch, E., Yhoung-Aree, J., Friend, R. and Funge-Smith, S. J. 2003. The role and nutritional value of aquatic resources in the livelihoods of rural people - a participatory assessment in Attapeu Province, Lao PDR. *FAO Regional Office Asia and the Pacific*, *Publication No. 2003/11,* Bangkok. 34 pp.

Mills, D. J., Westlund, L., De Graaf, G., Kura, Y., Willman, R. et al. 2011. Under-reported and undervalued: small-scale fisheries in the developing world. In: *Small-scale fisheries management: frameworks and approaches for the developing world*. R. S. Pomeroy and N. Andrew (eds.), pp. 1–15. CABI, Wallingford.

Morand, P., Sy, O. I. and Breuil, C. 2005. Fishing livelihoods: successful diversification, or sinking into poverty? In: *Towards a new map in Africa*. B. Wisner, C. Toulmin and R. Chitiga (eds.), pp. 71–66. Earthscan, London.

Moreau, J. 1979/80. Le lac Alaotra à Madagascar: cinquante ans d'aménagement des pêches. *Cahier ORSTOM*. *Hydrobiologie* 3–4, 171–179.

Okpara, U. T., Stringer, L. C. and Dougill, A. J. 2016. Lake drying and livelihood dynamics in Lake Chad: unravelling the mechanisms, contexts and responses. *Ambio* 45, 7: 781–795.

Pauly, D. 1990. On Malthusian overfishing. Naga, *The ICLARM Quarterly* 13, 1: 3–4.

Pidgeon, M. 1996. An ecological survey of Lake Alaotra and selected wetlands of central and eastern Madagascar in analyzing the demise of Madagascar pochard *Aythya innotata*. *WWF/Missouri Botanical Garden*, Antananarivo, Madagascar. 139 pp.

Pomeroy, R., Parks, J., Pollnac, R., Campson, T., Genio, E. et al. 2007. Fish wars: conflict and collaboration in fisheries management in Southeast Asia. *Marine Policy* 31, 6: 645–656.

Rakotoarisoa, T. F. 2018. Use of water hyacinth (*Eichhornia crassipes*) in poor and remote regions – a case study from Lake Alaotra, Madagascar [dissertation]. *University of Hildesheim*. 142 pp.

Ratsimbazafy, J. H., Ralainasolo, F. B., Rendigs, A., Contreras, J. M., Andrianandrasana, H. et al. 2013. Gone in a puff of smoke? *Hapalemur alaotrensis* at great risk of extinction. *Lemur News* 17, 14–18.

Razanadrakoto, D. R. and Rafaliarison, J. 2005. Délimitation des zones de frai dans le lac Alaotra. *Durrell Wildlife Conservation Trust*, Antananarivo. 45 pp.

Sarch, M. and Allison, E. H. 2000. Fluctuating fisheries in Africa's inland waters: well adapted livelihoods, maladapted management. In: *Microbehavior and macroresults.* Proceedings of the 10th Conference of the Institute of Fisheries Economics and Trade (IIFET), July 10–14, Corvallis, USA.

Schuhbauer, A. and Sumaila, U. R. 2016. Economic viability and small-scale fisheries — a review. *Ecological Economics* 124, 69–75.

Sievanen, L. 2014. How do small-scale fishers adapt to environmental variability? Lessons from Baja California, Sur, Mexico. *Maritime Studies* 13, 1: 9.

Smith, L. E., Khoa, S. N., and Lorenzen, K. 2005. Livelihood functions of inland fisheries: policy implications in developing countries. *Water Policy* 7, 4: 359–383.

Sneddon, C., Harris, L., Dimitrov, R. and Özesmi, U. 2002. Contested waters: conflict, scale, and sustainability in aquatic socioecological systems. *Society and Natural Resources* 15, 8: 663–675.

Sonwa, D.J., Dieye, A., El Mzouri, E. H., Majule, A., Mugabe, F. T. et al. 2016. Drivers of climate risk in African agriculture. *Climate and Development* 9, 5: 383–398.

Sultana, P., Anh, V. T. and Chiem, N. N. 2003. Understanding livelihoods dependent on inland fisheries in Bangladesh and Southeast Asia. *Vietnam country status report*. https://www.worldfishcenter.org/content/understanding-livelihoods-dependent-inland-fisheries-bangladesh-and-southeast-asia-vietnam. October 6, 2017.

UNDP 2016. Human development report. Human development for everyone. *United Nations Development Program*, New York. 271 pp.

Van Zwieten, P. A. M., Goudswaard, P. C. and Kapasa, C. K. 2003. Mweru-Luapula is an open exit fishery where a highly dynamic population of fishermen makes use of a resilient resource base. In: *Management, co-management or no management? Major dilemmas in southern African freshwater fisheries. 2. Case studies*. E. Jul-Larsen, J. Kolding, R. Overå, J. Raakjær Nielsen and P. A. M. van Zwieten (eds.), pp. 1–33. FAO Fisheries Technical Paper. No. 426/2, Rome.

Wallace, A. P. C. 2012. Understanding fishers' spatial behaviour to estimate social costs in local conservation planning [dissertation]. *Imperial College London*.333 pp.

Wallace, A. P. C., Milner-Gulland, E. J., Jones, J. P. G., Bunnefeld, N., Young, R. et al. 2015. Quantifying the short-term costs of conservation interventions for fishers at Lake Alaotra, Madagascar. *PLoS One* 10, 6: e0129440.

Wallace, A. P. C., Jones, J. P. G., Milner-Gulland, E. J., Wallace, G. E., Young, R. et al. 2016. Drivers of the distribution of fisher effort at Lake Alaotra, Madagascar. *Human Ecology* 44, 1: 105–117.

Webb, N. P., Marshall, N. A., Stringer, L. C., Reed, M. S., Chappell, A. et al. 2017. Land degradation and climate change: opportunities for building climate resilience in agriculture. *Frontiers in Ecology and the Environment* 15, 8: 450–459.

Welcomme, R. L. 2001. *Inland fisheries: ecology and management*. Blackwell Science, Oxford. 384 pp.

Welcomme, R. L., Cowx, I. G., Coates, D., Béné, C., Funge-Smith, S. et al. 2010. Inland capture fisheries. *Philosophical Transactions of the Royal Society B: Biological Sciences* 365, 1554: 2881–2896.

World Bank 2012. Hidden Harvest: The global contribution of capture fisheries. *World Bank, REPORT NO. 66469-GLB*, Washington, DC. 69 pp.

World Bank 2017. Countries and Economies: Madagascar. *World Bank*, Washington, DC. https://data.worldbank.org/country/madagascar. October 6, 2017.

Youn, S. J., Taylor, W. W., Lynch, A. J., Cowx, I. G., Beard, Jr., T. D. et al. 2014. Inland capture fishery contributions to global food security and threats to their future. *Global Food Security* 3, 3: 142–148.

5.7 Appendix

Appendix 13. Interviews performed with the Alaotran fishermen. Interviews comprise 41 questions and were performed with 117 fishermen at Lake Alaotra.

Appendix 14. Results from the interviews with Alaotran fishers (n = 117) showing the number of respondents and the percentage (%) of respondents for each question.

Appendix 15. Fishing trip duration. Median time for travel, fishing and total trip (hh:mm) indicated by Alaotran fishers from Andilana Sud, Anororo, Vohimarina and Andreba for the dry season (DS) and wet season (WS).

Chapter 6

SYNOPSIS

6.1. The Alaotra wetlands – one system, multiple conservation perspectives

This thesis focused on the evaluation of the current state and future trends of the ecology, resource use and nature protection at Lake Alaotra. Including ecological as well as socio-economic aspects of conservation planning, this research gained important insights into the different dimensions in conservation planning at the Alaotra wetlands.

From three perspective the key results are:

i. *From an ecological perspective* – Assessing the ecological state of Lake Alaotra, based on water quality and vegetation parameters (**Chapter 3**). The ecological state of the wetlands water body and vegetation is increasingly deteriorated by anthropogenic pressures. Human activities promote the encroachment of invasive and disturbance tolerant plant species that suppress native species. The destruction of the marsh belt disturbs its natural function as a buffer strip for nutrients and sediments. In this context signs of nutrient enrichment (eutrophication) as well as oxygen depletion occurred. During the dry season low water levels result in high water temperatures and hypoxic conditions.

ii. *From a nature protection perspective* – Evaluating the efficiency of Park Bandro regarding its small size and its community-led management as an example for local nature protection (**Chapter 4**). Park Bandro is struggling with elite capture, illegal activities within the protected area, small financial benefits and a lack of local legitimacy; issues that are particularly widespread in developing countries in the tropics. Thanks to the high regeneration potential of the wetland vegetation, the Park itself is nonetheless able to maintain an intact vegetation within its core area. Its long-term viability, however is endangered by a lack of connectivity and its diminishing size.

iii. *From a livelihood perspective* – Investigating the drivers of overfishing, fishers' vulnerability and livelihood strategies (**Chapter 5**). Current trends of population growth, land use change and climate variability oblige large parts of the Alaotran population to enter the fishery sector despite its declining productivity. At present the small-scale fishery of the lake fulfils a safety net function which is crucial for local people's livelihood security and their social environment. The ongoing livelihood dynamics however, may strain this safety net to its breaking point: the increasing human pressure may exceed fish stock regeneration capacity and let people 'fall' into a poverty trap.

The key results presented above indicate that the Alaotra region is undergoing major changes. The dynamics involved are either of social, economic or of ecological origin. Their effects however, extend far beyond one dimension and form a complex set of interactions (Figure 6.1).

In the past, research has often addressed either ‘ecosystem production or protection’. However, ecosystems are mostly allocated to both resource use and nature protection activities (Daily 2000, Mander et al. 2007). As a consequence of such one-sided approaches, interrelations and trade-offs between management, ecology and resource users often remained unheeded or even undiscovered. Furthermore, apparently similar terms such as 'conservation' or 'sustainable development' may have a different meaning for ecologists, conservationists and economists (De Groot 1987).

The following section synthesizes the results from different conservation perspectives at Lake Alaotra to understand current changes and dynamic as well as their origin. This research (i) provides an overall profile of the Alaotra wetland state, (ii) discloses trade-offs between the dimensions of wetland conservation planning and (iii) identifies future trends. Hereby, this thesis makes a substantial contribution to the future conservation management of the Alaotra wetland system and tropical wetlands as a whole. The overall wetland profile will serve as a basis for both, local wetland management and research. The data on Lake Alaotra’s ecological state provided in this study are the first since two decades (**Chapter 4**). It will help to appraise its actual capacity to support biodiversity and provide ecosystem services to the local population. Moreover, the research continues to meet the urgent need for basic and directed information about wetland state, use and values (Rebelo et al. 2010), especially in priority areas, such as the Alaotra region (cf. Finlayson et al. 1999). By disclosing trade-offs between the different dimensions in wetland conservation, this research draws attention to present challenges which hinder management practices to be effectively applied. Being aware of future trends in the Alaotra wetland system, this thesis furthermore helps to achieve an integrated view on the required adjustments and innovation in the wetland management. Overall this research will help develop more effective management strategies, that contribute to minimize conflicts and ensure that environmental conservation and poverty reduction are most likely to be achieved.

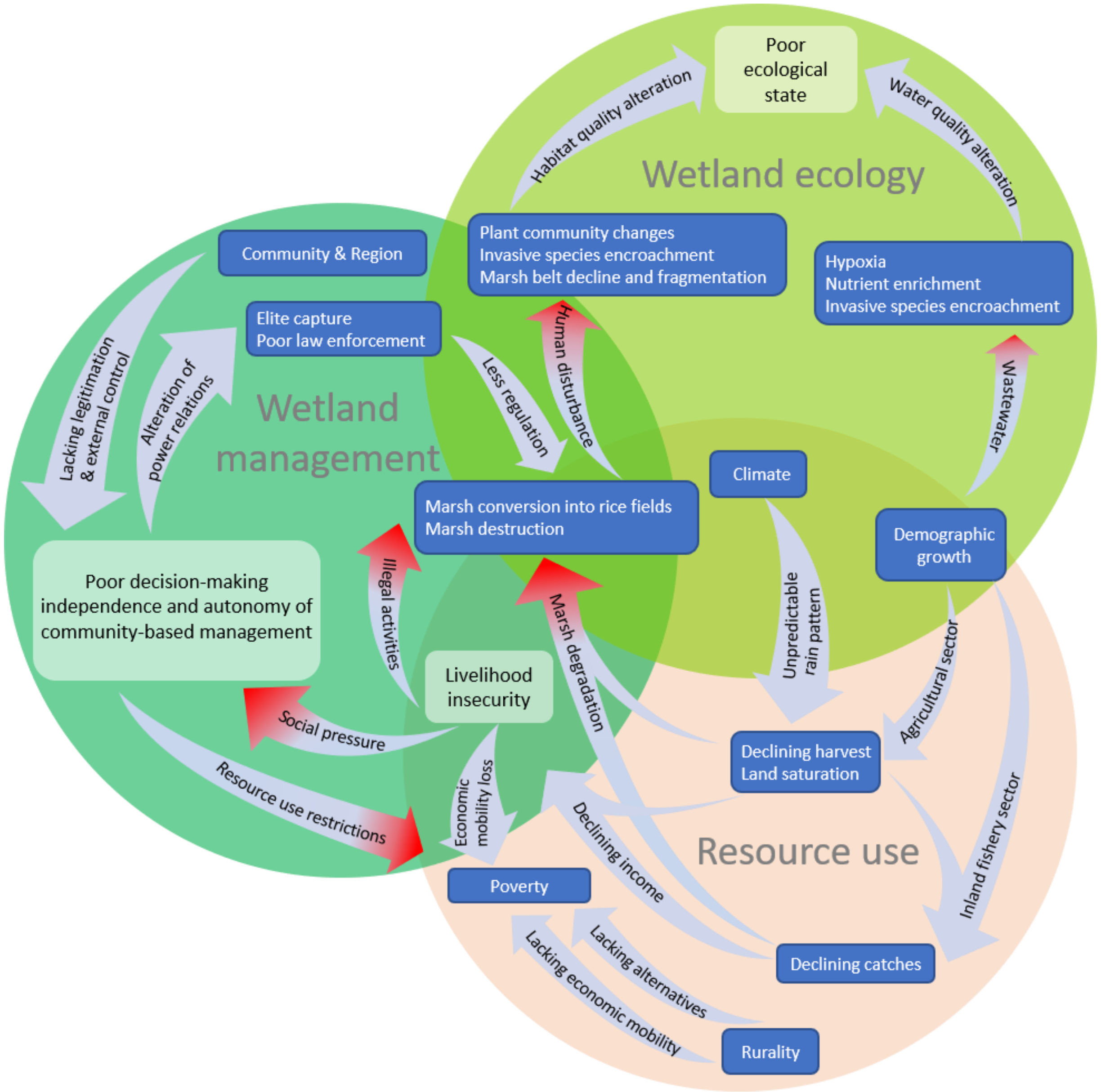

Figure 6.1. Interrelations (blue arrows) and existing trade-offs (red arrowheads) between different dimensions of conservation planning - the Alaotra wetlands ecology, the local resource users and local nature protection. For the purpose of clarity, the figure shows only direct interrelations which were disclosed by this study and may therefore not indicate all interactions.

6.2. Conservation perspectives – status quo, interrelations and trade-offs

What are the visible and hidden consequences of the dynamics shown in Figure 6.1. and what do the recent trends indicate for the future development of the Alaotra wetland system?

The human population grows increasingly rapid at Lake Alaotra. Subsequent dynamics such as land use change, fish catch decline or human induced wetland degradation thus follow a similar pattern, albeit with some delay. About two decades after the last comprehensive ecological study by Pidgeon (1996), the indicators of the anthropogenic disturbance therefore point towards a strong and increasingly rapid alteration of the wetland ecology. This becomes particularly evident when we juxtapose the marshland area reduction with the human population growth during the last century: of formerly 75.000 ha marsh vegetation that existed in 1949 only 23.000 ha are remaining today (Riquier and Ségalen 1949, Ratsimbazafy et al. 2013). This marshland area is subjected to interventions by a population that has increased more than fivefold during the same time period (Pidgeon 1996, Ratsimbazafy et al. 2013). In this context it is important to understand, that the almost universal wish of rural Malagasy people to have many offspring can neither be explained by lacking formal education nor by economic or social security strategies; instead it represents their understanding of a meaningful life (Keller 2009).

If the current dynamic of marsh shrinkage will continue to the same extend, I assume that within the next three decades the wetlands might be reduced to a few remaining patches. My results showed already a noticeable fragmentation of the marsh belt in more densely populated areas (Anororo): here, the fringing vegetation of the marsh belts has been cleared to less than 50% cover (see **Chapter 3**). The increasingly densely populated lakeshore alongside the thinning marsh belt will further amplify the progressive water quality deterioration of Lake Alaotra in the future. The insufficient sanitation in the villages nearby the lake and the shrinking marshes, which high nutrient uptake normally acts as a filter between land and water body (see Barling and Moore 1994), leads to in an increasing amount of municipal wastewater being directly discharged into the lake (see Figure 6.1.). This also increases the health risk for the local population, especially since a large part of the people work at and in the lake. Most of all, it can result in a depletion of oxygen in the water. In Anororo hypoxia was detected during the rainy season, when the lake expands and large parts nearby the village are flooded. Under these conditions hypoxia tolerant non-native fish species might therefore have an advantage over native and locally endemic fish species (**see Chapter 3**).

Apart from the water quality alteration and overall wetland connectivity loss, the anthropogenic pressure at Lake Alaotra manifests in changes in the plant community composition and structure

(**Chapter 3** and **4**). This finding is not surprising, since human disturbance is a key factor regulating the wetland type and its biological community (Keddy, 2010). Particularly in areas where either human density is high or accessibility is easy the plant community has experienced a shift in dominance towards invasive and disturbance tolerant plant species. Notably, the encroachment of the invasive water hyacinth and the water ferns (namely the invasive giant aquatic fern, *Salvinia molesta*) will have considerable impact on the wetland ecosystem (**Chapter 3**) and human livelihoods in the future (cf. Rakotoarisoa 2018). The two species are among the most invasive species worldwide and exhibit similar ecological behavior (Patel 2012, Luque et al. 2013). Both are highly productive and competitive aquatic plants, flourishing especially in shallow, nutrient rich waters. Their dense floating mats reduce the water flow, clog waterways and alter water quality by lowering the light penetration and oxygen content (Gunnarsson and Petersen 2007, Luque et al. 2013). As human interference, such as nutrient enrichment and physical disturbance favors their spread and establishment (Gunnarsson and Petersen 2007, Gettys et al. 2014, Rakotoarisoa 2018), their proliferation around the lake shore is expected to proceed quickly in the next years (see Figure 6.1.). The results of this thesis have shown that the water hyacinth already dominates more than 50% of the lake shore vegetation at Anororo, the study side at Lake Alaotra which has been classified as the most degraded. The water ferns represent around one third of the fringing marsh belt vegetation at the study site with intermediate degradation (Andreba) (see **Chapter 3**).

At other African lakes and waterways, the rapid proliferation of the two aquatic macrophytes has already caused major problems (Villamagna and Murphy 2010, Patel 2012). When *Salvinia molesta* covered 25% of Lake Naivasha`s water surface in 1988 (Njunguna 1992) it led to massive problems for the lake’s flora and fauna, transport and fishery (Howard and Harley 1997). During the late 1990s the water hyacinth covered 90% of Lake Victoria’s shoreline (Mogaka et al. 2005) and caused the deoxygenation of the water, especially of the nursery grounds of the shallow bays, and hereby caused an overall reduction of the fish stocks. The plant further disrupted the native aquatic plant community, hampered transportation and fishing activities, impeded water supply to humans and hydro power stations and provided habitat to disease vectors that pose a risk to human health (Howard and Harley 1997, Gichuki et al. 2001, Kateregga and Sterner 2007). According to Mogaka et al. (2005) the water hyacinth cost the Kenyan economy during the peak of its infestation in Lake Victoria from 1996–98 annually one million US$ losses in local fishery, and 25,000 US$ in additional fuel costs for ferries while the Ugandan Electricity Board lost 1 US$ million per day due to clogged hydro power stations (Bethune and Roberts, 2002).

Although the water hyacinth and the water fern have been controlled successfully in many lakes and waterways (including Lake Naivasha and Lake Victoria, cf. Otiang'a-Owiti and Oswe 2007 and Albright et al. 2004, respectively) the control mechanisms are either costly (e.g. mechanic control) or risky due to unpredictable side effects (e.g. biological and chemical control) (c.f. Rakotoarisoa 2018). Moreover, the success is highly site dependent (cf. Malik 2007, Villamagna and Murphy 2010). Koutika and Rainey (2015, p. 270) therefore emphasize in their review on both species, that the "*utilization of the species could serve as a positive approach to control E. crassipes, especially in the developing countries*". A recent study conducted by Rakotoarisoa et al. (2015, p. 128) on the beneficial use of the water hyacinth at Lake Alaotra likewise describe the control of the plant as "*unrealistic due to institutional and financial limitations in Madagascar*". The author identified compost and handicraft as appropriate use option for the poor and rural region (Rakotoarisoa 2018). However, convincing the local population at Lake Alaotra to use the water hyacinth is challenging: their poverty and high vulnerability as well as their limited access to financial resources has to be considered for a successful implementation. In this process, in particular the production time and the cost incurring in the beginning as well as the local skepticism towards innovations must be overcome (Rakotoarisoa 2018).

Even in case of water hyacinth use, the fast growing human population is likely to trigger further wetland disturbance. Considering this trend, the spread of the invasive aquatic plants and the overall disturbance related changes in the plant community are expected to continue (see Figure 6.1.). These changes entail diverse negative consequences for the aquatic and terrestrial ecosystem as well as for the resource users at Lake Alaotra. As discussed in **Chapter 4** in detail, the plant community shift deteriorates habitat quality for the locally endemic Alaotran gentle lemur. Large mats of the water hyacinth further alter the water quality and thereby the aquatic community, as observed in many other lakes (Malik 2007, Patel 2012, Aloo et al. 2013, Coetzee et al. 2014). As other studies indicated, the dense mats can also impede foraging of birds (cf. Harper et al. 2002) and may even lead to changes in the seasonal waterbird community (cf. Villamagna et al. 2012). My results moreover suggest that the dense mats may be responsible for the displacement of native plant species by restricting them from light and pressing them physically down (**Chapter 3**) as reported for other lakes and streams (cf. Gichuki et al. 2001, Brendonck et al. 2003). Already today, studies show that, the resource users at Lake Alaotra are affected by clogged waterways and fishing areas which oblige them to create new channels and open areas within the marshes, thereby additionally triggering disturbance (Wallace 2012, Rakotoarisoa at al. 2015).

Small protected areas effectively reduce the disturbance driven shift in the plant community and structure of the marsh vegetation at Lake Alaotra. This has been proven by the comparison of the small protected area Park Bandro and the area outside the park boundaries (**Chapter 4**). A higher and denser vegetation inside the protected area as well as a considerably lower proportion of invasive species (2.9% within the park vs.25% outside the park) and a lower proportion of open water areas (4.8% of open water areas within the park vs. 21% outside the park) result in a more intact marsh belt and hence, a higher habitat quality (**Chapter 4**).

These results are of enormous importance since the small protected area hosts the largest remaining population of the locally endemic Alaotran gentle lemur (*Hapalemur alaotrensis*) which number has decreased around the lake by 75% between the 90s and the early 2000s. Latest data from 2005 suggest that only 2500 individuals are left (Ralainasolo et al. 2006). Despite this rapid decline and the large concern about the future of this species, current data on the species population size are missing (Ralainasolo et al. 2006, Ratsimbazafy et al. 2013). In this context, the evaluation of Park Bandro (**Chapter 4**), which aims to protect the Alaotran gentle lemur is highly needed. The results will help the wetland management authorities to appraise the potential, weaknesses and limitations of small protected areas and community-led management. On a broader scale, the gained knowledge will serve the worldwide call for protected area effectiveness evaluations (c.f. Hockings et al. 2006, Leverington et al. 2010): on the one hand, resources are continuously invested into the establishment and management of protected areas all over the world (Chape et al. 2008). On the other hand, protected area management is increasingly confronted with socio-economic, biophysical and institutional global change impacts and trends (Shadie and Epps 2008).

The findings of this study show that first, small-scale conservation areas can be a valuable option for conservation in human-dominated landscapes with high natural resource dependencies, as it is the case for many other areas (cf. Cowling and Bond 1991, Götmark and Thorell 2003, Bodin et al. 2006). The more intact vegetation offers retreat for animal species, nest sites for mammals and birds, and a higher locomotion potential for terrestrial species (see **Chapter 4**). Second, the findings of this study indicate that the park offers enough habitat for species with a small home range like the Alaotran gentle lemur (see **Chapter 4**). On the other hand, regarding the long-term conservation targets of Park Bandro, the management has to consider the limitations of the park. It is highly vulnerable to anthropogenic changes on its outside due to its small size and suffers by a highly disrupted connectivity due to its ever-increasing isolation within the surrounding matrix of human-used land. Under current conditions, gene flow between populations and escape of individuals in case of habitat destruction by fire, the main threat to the lemur, is impossible (Ratsimbazafy et al. 2013). An increasing population density inside the park will further lead to inbreeding, genetic drift, intraspecific competition and density stress, and finally decrease genetic diversity. In addition, plant dispersal and various other ecological processes are impaired due to the disrupted connectivity of Park Bandro (see **Chapter 4**).

Linking the results of the wetland's ecology (**Chapter 3**) and its locally managed protected area (**Chapter 4**) with the ongoing changes in livelihoods (**Chapter 5**), a more comprehensive perspective on the future trends of the Alaotra wetland system is possible. The current economic trends will increase the anthropogenic pressure on the protected area as well as on the overall wetland system: due to the declining agricultural productivity and lack of arable land, the local population expands the agricultural area into the marshes and increasingly also enters the inland fishery sector as secondary profession (see **Chapter 5**, cf. Figure 6.1). Already today, illegal rice cultivation constitutes one of the main pressures for the protected area Park Bandro (**Chapter 4**). The growing fishing activities and overall wetland decline due to marsh conversion into agricultural land will not only lower habitat quality for terrestrial species but also lead to the destruction of spawning sites and impair the ecological buffer function (nutrient removal and sediment retention) of the marsh belt (see **Chapter 3**). This is a general issue for wetlands within Sub-Saharan Africa: 93% of the Ramsar wetlands in this region are used for agriculture and fisheries while 71% of these sites are threatened by these activities (Rebelo et al. 2010). According to Schuyt (2005) demographic growth, poverty and economic stress are the main pressures on African wetlands, as they are the main drivers for the overuse of resources by local people. My study on the Lake Alaotran small-scale fishery (**Chapter 5**) has identified livelihood insecurity as a key determinant for overfishing coming along with conflicts and competition over livelihood opportunities, fishing places and gear as well as with income decline and increasing poverty (**Chapter 5**). Local inhabitants use fishing as a rural adaption strategy to cope with declined yields in crop production due to soil fertility loss and erosion, lacking agricultural land, low investment capacities, fluctuating prices and high intra- and inter-annual changes of the rainy season (see **Chapter 5** for detailed information). However, at Lake Alaotra, agriculture and fishery are suffering substantial losses simultaneously, driving farmers to engage in fishing and vice versa. Lacking alternatives hinder them to exit and instead trap them in declining sectors (see **Chapter 5**). The statement from Rebelo et al. (2010, p.558) saying that "*it is very likely that further development of wetlands for agriculture will be difficult* *to prevent when alternative livelihood opportunities are lacking*" could thus be extended to the fishery sector for Lake Alaotra.

The economic status is a crucial factor for the success of protected areas, not only in Madagascar. In Indonesia for example, the economic crisis in the late 90s was followed by increased illegal logging and protected area encroachment (Resosudarmo 2004). Resource dependence is a heavy burden for nature conservation efforts (cf. Fu et al. 2004). According to Fa et al. (2003), in four of five studied Congo Basin countries forest mammals are highly threatened by people's dependence on bushmeat protein since the region cannot produce sufficient alternate protein sources to prevent protein malnutrition of the human population. A broad-scale evaluation from Barnes et al. (2016), about the abundance trends of wildlife within 447 protected areas all over the world showed, that wildlife population trends are more positive in countries with greater human wealth and development.

A recent study from Borgerson et al. (2018) confirms the described economic trends in this thesis: although annual incomes in the Alaotra region are comparatively high for Madagascar, 98% of the people are affected by food insecurity. The authors found that high food insecurity resulted in a significantly higher rate of forest and marshland mammals illegally hunted and eaten per household. Besides tenrecs (97.2%) and civets (1.2%) the Alaotra gentle lemur represented 1.6% and thus 16 individuals, that were illegally hunted during the prior year.

The trade-offs between nature protection, ecosystem functioning and human needs calls for an effective management as the human activities will soon exceed regeneration potential of the park's highly productive marsh vegetation. Outside the community protected area, the marsh belt is already highly fragmented and degraded, and the extent of overfishing at Lake Alaotra has exceeded the regeneration capacity of the fish stocks since the majority of individuals is caught before reaching maturity (**Chapter 5**).

Despite the importance of the management efficiency, my findings show that it currently displays significant shortcomings, notably a poor law enforcement and lacking legitimation among the local population (**Chapter 4**). Limited financial resources for equipment and staff, as is often the case in developing countries (cf. Andrade and Rhodes (2012) are certainly one reason for these deficiencies. Additional important factors turned out to be the insufficient understanding of resource users and incorporation of knowledge about traditional norms and social hierarchies in management policies (**Chapter 4** and **5**; see also Fritz-Vietta et al. 2009). Though illegal marsh destruction and the use of destructive fishing methods are penalized with fines, the existing kinship network and other power relations in Madagascar demand 'solidarity' and may discourage local inhabitants to disclose perpetrator identity (**Chapter 4**). Kinship (*fihavanana*) defines a "*person's identity and place in society*" (Keller 2009, p. 83, see also Fritz-Vietta et al. 2011 for detailed information). Land ownership, family and class relations as well as other power relations are often kin-based and reflect its importance in the Malagasy society (Jarosz 1991, Fritz-Vietta et al. 2011, Huff 2014). When livelihoods are becoming insecure, as it is the trend at Lake Alaotra, people are likely to attach a greater importance to social relations rather than laws and rules (see Figure 6.1.). Fritz-Vietta et al. (2011, p. 222) exemplifies this fact by means of a Malagasy proverb: "*Aleo very tsikalakalamkarena toy izay very tsikalakalampihavanana* [Better to lose some material wealth than losing the relationship with kin or friends]".

A meta–analysis from Andrade and Rhodes (2012) has shown, that indeed the economic status as measured by the gross domestic product per capita, is positively related (albeit not significant) to local populations' compliance level with protected area regulations. However, the explaining and most significant factor for local populations' compliance is the level of participation. According to this, local community participation is crucial for the successful governance and management of natural resources. Peoples involvement through participatory approaches aims to ensure their empowerment as well as an equal status in decision-making processes and an equal share of benefit. This is currently not the case for the participatory management of Park Bandro. The community-management first of all encourages or condones illegal marsh destruction and second, favors elites while disadvantaging the poor. The majority of cash benefits generated by the park are made by illegal rice cultivation within the park and in addition by people who are involved in the management of the park (**Chapter 4**). Given these points, the present community-management undermines the policy objectives of community-based development and sustainable wetlands management (cf. **Chapter 1**). Moreover, it can be deduced that, the roots of the poor law enforcement and lacking legitimations of the community-managed Park Bandro are at least partly entrenched in the fact that, members of the associations advocating the park's protection status are in reality capturing resources and violating rules instead of obtaining their enforcement.

Elite capture and political clientelism is a common phenomeoein developing countries (cf. Platteau 2004) and often beyond the major critique of participatory approaches, such as community-management (Brooks et al. 2013, Lund and Saito-Jensen 2013, Waheduzzaman et al. 2018). As explained by Saito-Jensen et al. (2010), formal structures, given to guide local associations' activities in order to meet the desired goals are often 'translated' by members into actions fulfilling their own interests. Social relations tying members to common ideas and interests may brought to life through the association and lead to outcomes opposed to the original objectives. The author further clarifies that "*elite capture is not necessarily created by participatory approaches, but is rather an unintended result of the inequality and hierarchies that existed prior to the introduction of these approaches*" and that may lead to the "*further oppression and marginalization of the already marginalized*" (ibid, p. 328). Since the 'western-style' management plans and maps favor people with higher literacy level, better educated stakeholders do often outcompete less formally educated groups, including in particular the poor but also legitimized villagers such as the elders of the community (Pollini and Lassoie 2011).

The present community-management may hence increase the gap between local elites or financially powerful actors and the poor or marginalized people of the community. Further, current natural resource management cannot address the needs of the poor people if they are excluded from decision-making processes. This is especially unfavorable since poor people often tend to use unsustainable practices due to a lacking economic mobility (cf. Clark 2012, Lynch et al. 2017). Within this thesis, we investigated that fishers that do not have cultivation area and are thus bond to a declining fishing sector, run the risk to be trapped in poverty. Temporary resource use restrictions, such as the two-month fishing closure especially affect poor people and are likely to increase their economic immobility (see Figure 6.1.). The fishing closure aims to increase the fish stock regeneration capacity but might also trigger the use of destructive fishing methods. In this research we identified inland fishery serving as a safety net for the poor and thus holding a crucial function for human well-being. Further financial losses increase people's vulnerability to financial shocks (e.g. illness, climate hazards) and might force them to switch to even more unsustainable and destructive fishing methods (cf. **Chapter 5**).

This thesis has unveiled numerous trade-offs within the Alaotran wetland policy, people and livelihoods. Aspects such as demographic growth, climate change, traditional culture and social hierarchies as well as the very survival of people are currently threatening the success of the Alaotran wetland policy. The case of Lake Alaotra poses an example for the overall African wetland policy, that has neglected human socio-economic needs and has largely been driven by environmental concerns (Wood et al. 2013). Since the majority of the African population continues to live in rural areas and future trends point towards increasing food insecurity which is further enhanced by climate change (Binns et al. 2011, IPCC 2014), the incorporation of the wetlands role for peoples' livelihoods into wetland policy and management initiatives is crucial.

6.3. Perspectives in practice – recommendations for wetland management and future research directions

Although management measures have tried to promote sustainable resource use, the Alaotra wetland's marsh belt and the fish stock are declining while the overall ecological state of the wetlands is concerning. Despite the fact that wetland policy and management initiatives have tried to incorporate local people's interests by participatory approaches, the environmental management lacks success and legitimation. And although the Alaotra wetlands are a leading economic region in Madagascar, the local population is affected by food insecurity and people find themselves in declining sectors.

Those discrepancies between conservation planning and reality illustrate that the effectiveness of the wetland management is hampered by a complex setting of interrelations and trade-offs resulting from different perspectives (see **Chapter 6**). Based on the findings of this thesis, I aim to contribute to the better understanding and incorporation of prevalent perspectives in conservation planning for wetlands in developing countries. Following recommendations can be drawn from this thesis for the wetland management and research:

Management strategy selection: worldwide, the growing population is escalating the pressure on wetlands in order to improve food security. The anthropogenic impact can entail drastic repercussions for people that depend on ecosystem goods and services (McCartney et al. 2010). On a long-term, the negative economic consequences of wetland modification and reclamation can be far greater than the direct benefits for local people (Schuyt 2005). At Lake Alaotra, the high level of wetland resource exploitation has led to the decrease of economic returns (see **Chapter 5**). Local people compensate livelihood insecurity by unsustainable resource use, which in turn has tremendous impacts on human behavior, the social environment as well as ecosystem properties and leads to an overall increased vulnerability of communities (FAO 2016). Indications for this trend are already observed among fishermen at Lake Alaotra (**Chapter 5**). Regulations for a sustainable wetland resource use are thus essential for local livelihoods and human well-being.

In regions with a high resource dependency like the Alaotra region, biodiversity conservation and poverty reduction are closely linked to sustainable resource use management. However, management strategies should be clear about the goals of biodiversity conservation and poverty elimination which are, though being generally positively linked with each other, not always fully compatible (Hannigan 2006, Ferraro et al 2011, Karimi et al. 2017). The incorporation of socio-economic conditions and the strengthening of the local management are needed to decide between different conservation strategies for the Alaotra wetlands. According to Adams et al. (2004) management (1) may see poverty and conservation as separate policy realms, (2) may consider poverty as a critical constraint on conservation, (3) can follow a position that recognizes conservation as a primary goal which however should not compromise poverty reduction or, (4) starts from the view that poverty reduction depends on living resource conservation. The development of a more effective management for the Alaotra wetland system will be facilitated if the fundamental goals are clearly defined. Moreover, the interaction between present conservation agencies as well as between different stakeholders will be easier if the different positions are fully understood.

Incorporation of socio-economic development: Based on the result of this thesis, I recommend to adjust incentives to manage wetland resources to the prevalent socio-economic development. In particularly tropical wetland ecosystems are deeply intertwined with the livelihoods of the people.

Tropical wetlands present highly productive ecosystems that are mostly located in rural areas characterized by lacking infrastructure, market access and financial capital. In those areas where livelihood alternatives and people's economic mobility are poor, wetlands do often – especially in comparison to other ecosystems – play a particular critical role in human livelihoods (McCartney et al. 2010, Wood et al. 2013, Langan et al. 2018). This thesis has shown, that the Alaotran fishery secures livelihoods in times where agriculture, the main economic sector at lake Alaotra, struggles with declining yields and lacking arable land. Understanding the current socio-economic function of the fishery for local livelihoods, it becomes plausible that the resource users' need for daily cash income is pivotal for their decisions and incompatible with the current two-month lasting fishing closure. In the same vein, reasons for wetland reclamation for agriculture is becoming evident. In this context many studies underline that the incorporation of social values and preferences as well as economic needs and interests, whether in favor or against conservation goals, are likely to create more realistic conservation strategies by displaying trade-offs between biological and socio-economic objectives (Naidoo et al. 2006, Klein et al. 2008, Karimi et al 2017, Hanspach et al 2017, Regos et al. 2018). Bringing existing trade-offs to the fore will induce decision makers to create a management plan which is more adapted to the local needs.

At Lake Alaotra, the trade-off between the fishers' need of a daily cash income and the two-month fishing closure illustrates the imperative of considering resource users socio-economic demands. Management authorities, namely the Federation of Fishers (*Fédération des Pêcheurs*) failed to ensure the promised financial support for fishers during the temporal fishing closure (Wallace 2012). Fishers therefore continued to fish all year round and to overexploit their own base of existence. The spatial fishing closure better matches the fishers' need for a small but year-round income. However, a spatial fishing closure has not been implemented successfully up to now and the temporal fishing closure is exclusively applied.

Moreover, my results indicate that the fishery sector often serves as livelihood for landless people without other livelihood opportunities or to earn additional income due to declining yields in agriculture. As increasingly recognized, temporal resource restriction often unproportionable hit the poor and will rather trigger the use of destructive methods and illegal fishing than fish stock regeneration (cf. McClanahan et al. 2005, FAO 2017). Spatial fishing closures would distribute costs and benefits more equal around the lake and reduce cost for fishers (cf. Wallace 2012). By ensuring a continuous income, the fishers' compliance with regulations is more likely to be achieved.

Additionally, the economic development points out, that the decreasing productivity in fishery and agriculture will successively lower investment capacities of fishers. This development makes a self-motivated investment in legal gear and abandoning of illegal methods increasingly unlikely. Gear exchanges free of charge for fishers practicing illegal and destructive methods can help to lower the exploitation of juvenile fishes, encourage compliance with existing gear restrictions and reduce social tension (cf. Cinner 2010).

A study from Rebelo et al. (2010) on African wetlands further demonstrates, that the nature of household dependence on natural resources is highly site specific and changes with socio-economic status. Following the authors, wetland resource management has to be tailored to different locations but also to socio-economic groups within one community. It is therefore important to undertake further endeavors to understand the social and economic factors controlling wetland resource use at Lake Alaotra.

Economic valuation studies are an additional tool that can help to understand economic importance of wetlands. Hereby, decision makers outside the wetland, whose activities indirectly threat the wetland (e.g. dams, wetland conversion in agricultural land) may understand the greater economic benefits of sustainable wetlands resource use (Schuyt 2005). Meanwhile actors within the wetland could gain information on the economic role of different economic wetland activities for local population (ibid). This information will help wetland management authorities to contribute to a more sustainable management and to avoid economic inefficient decisions with high cost for the rural poor. In other words, such valuation studies can avert poverty alleviation strategies which are bond to economic development premises based on unsustainable short-term gains which are to the detriment of the wetlands long-term viability (Sanderson and Redford 2003). Since local people have a deeper understanding of the local economies, it is essential to include their expertise when carrying out valuation studies (Schuyt 2005).

Strengthening local management: A sustainable wetland management is critical for the long-term health, welfare and safety of the communities living around the Alaotra wetlands. However, it is very likely that "*only those policies which empower local people to manage and control the wetlands in their own landscape will be successful*" (Rebelo et al 2010, p. 571). The inefficiency of the current management is linked to a poor compliance to resource use regulations and incredibility of management authorities (**Chapter 4** and **5**). Considering how rule breaking behavior can be discouraged in local resource users will help local management to achieve a successful natural resource management (Keane et al. 2008). Enforcement strategies that minimize costs and maximize benefits for management and the local population should therefore be the focus of future research (ibid).

As it is the case for many community-based management approaches (see Section 4.4. in **Chapter 4**), at Lake Alaotra a genuine shift in authority to local people has been missed. Legitimate traditional leaders who derived authority from their ancestors and usual led decision-making processes in the community are largely excluded from the new management. Principles of rural community governance were neglected (**Chapter 4**). Consequently, management associations were created without any historical background or locally meaningful legitimation (Kull et al. 2002) and largely follow the 'western-style' management instead of traditional governance. Members often do not originate from the decision makers of the community and therefore do not necessarily include locally recognized members with experience in managing conflicts and leading decision-making processes. My results demonstrate that under the current membership regulations, a minority of privileged stakeholders can easily take power over the resource management association, whilst their local power relations (e.g. family, lineage, property) within the community are likely to influence or restrict access to associations for marginal local groups and residents with conflicting interests. As a result, we observed elite capture and an unequal distribution of benefits to the detriment of the poor (**Chapter 4** and **5**) instead of local development and poor people empowerment, which are among the principle objectives of community-based management.

Since external control in Madagascar is weak due to a lack of financial resources, capacity building for group leaders and members may help to increase internal control and transparency. The abilities acquired during such capacity training should include training in conflict solving and administration. These abilities could help them to acquire more competences in the management of their association, to strengthen their active involvement, help them to follow and to understand agreements and finally increase transparency and make members more accountable. Further, the integration of traditional forms of governance, including local knowledge systems such as dance, songs, storytelling, spiritual ceremonies will help to encourage the participation of less formal educated villagers and form a group which is more representative for the community (cf. Fritz-Vietta et al. 2011). The adoption of locally traditional culture, leaders and institutions may evoke a more inherent legitimation for resource management measures and will reduce social pressure. The participation of different social groups will contribute to a more equal distribution of benefits and prevent the generation of income from illegal activities which are only of use for a minority. Two additional steps might help to obviate elite capture: First of all, a "*sequential and conditional release of aid funds* [to] *discipline local leaders or intermediaries*" as it is recommended by Platteau (2004, p. 232). Second, the right to remove leaders of an association from their position between the official elections (taking place every three years) may curtails the leaders' power and can reduce risk of elite capture.

In order to create a fair basis for negotiation away from top-down decision-making to the real empowerment of the community, conservationists (e.g. NGO, policy makers) have to communicate openly about opportunity costs of the protected area and hence about the trade-offs of conservation (Fritz-Vietta et al. 2011, Measham and Lumbasi 2013, Pollini et al. 2014).

Human impact regulation: Current management comprises a variety of resource use regulations and restrictions in order to regulate the anthropogenic impact on the wetland biodiversity and on ecosystem functions. This thesis has shown, that a regular evaluation of management measures is needed in order to determine their success and long-term effectiveness, and to instigate appropriate changes and adaptations. In this context, clear and visible boundaries of the community-managed protected area, Park Bandro, can help to prevent or at least contain the successive unobtrusive expansion of agricultural area into the park. GPS data on the current demarcation of the parks boundaries and a regular control are preconditions for this. To ensure the long-term conservation of the Alaotra gentle lemur, it should be avoided to 'put all one's eggs into one basket': the lemur population living within Park Bandro is more and more isolated from other populations. Under these circumstances, the risk of genetic depletion is high; and moreover, any fire event, the main threat to the lemur, would wipe out right away the species biggest remaining population worldwide. The establishment of additional protected areas in the vicinity and corridors will help to maintain wetlands ecological connectivity. Equally important, it will support native plant and animal species, prevent the alteration of the plant community composition and structure (e.g. invasive species proliferation) and help to maintain important ecosystem functions. Moreover, preserving an intact marsh belt is necessary to balance the healthy functioning and the provision of ecosystem services and goods of wetlands to the local population in the future (Turner et al. 2008).

Despite the fact, that the community-based management approach itself restricts the size of a conservation area (see **Chapter 4**), this research has shown, that in absence of strong governmental institutions small-scale community management is nonetheless a more efficient option than large-scale conservation: Park Bandro represents an island in a relatively degraded environment. Since cultural, socio-economic and political interests differ at different sites, small-scale protected areas have been proven to facilitate decision-making at the local level (cf. Agrawal 2001, Brooks et al. 2013).

Besides the limitation of human activities, other regulations can help to reduce anthropogenic pressure, without imposing any restriction for local people. The influx of human wastewater represents a large pressure on the Alaotra wetlands, leading to hypoxic conditions and the spread of invasive species. Sanitation systems will help to decrease the nutrient entry in the lake, especially during the wet season when large areas around the lake are flooded. The use of the water hyacinth for compost and handicrafts could additionally reduce the anthropogenic pressure on the lake (Rakotoarisoa 2018). In order to enable handicraft women and farmers to apply those use options an adequate support during the implementation phase and beyond is crucial (cf. ibid).

6.4 Conclusions

Wetlands are multiple-value systems, harboring a large part of the world's biodiversity, playing a key role in hydrological and biogeochemical cycles and at the same time hold a critical role in livelihoods of millions of people, especially in developing countries (McCartney et al. 2010, Junk et al. 2013, Langan et al. 2018). Despite their importance, tropical wetlands are continuously degraded and suffer high loss rates. The inextricable bond between human livelihoods and the ecosystem health and the general gap in knowledge makes conservation management for wetlands in developing countries to a particular challenge. By combining research on ecology, resource use and management at Lake Alaotra, this thesis has disclosed conflicts between interests and needs, which are excluded in a one-sided consideration, but inhibit nature conservation and render it ineffective. Based on the findings of this thesis, some emerging aspects need to be highlighted for a successful conservation management of the Alaotra wetlands:

a) The continuously growing anthropogenic pressure on wetlands' ecosystems is reflected in plant community changes and water quality alteration. In order to further fill the knowledge gaps and enable targeted management strategies and interventions further research on the eutrophic state of the lake, nutrient uptake and retention by the marsh belt and occurring species is needed.

b) The establishment of additional community-managed protected areas and corridors is needed to guarantee long-term conservation of locally endemic species, such as the Alaotra gentle lemur (*Hapalemur alaotrensis*) and to maintain important ecosystem functions in order to ensure the provision of ecosystem services and goods to the local population in the future.

c) Resource use regulations ensuring a more equal distribution of cost and benefits will help to increase people's compliance with management strategies.

d) Building and protecting resource users' assets will help them overcome shocks and adapt to changes instead of drawing on destructive and unsustainable resource use methods.

e) The incorporation of socio-economic development is required in order to understand the current function of resource use for local populations livelihoods and to adapt management strategies.

f) Conservation planners (e.g. NGO, policy makers) need to get involved with local ideas and management concepts instead of sticking to global natural resource management practices to allow a genuine management transfer and development away from top-down decision-making.

g) To create a fair basis for negotiation an open communication about central goals of the management strategy and the opportunity costs is a basic prerequisite.

h) Long-term support and supervision of local management associations are required in order to build up trust, to develop side specific management tools, and to incorporate and link different perspectives.

Tropical wetlands are largely located in those parts of the world where human resource use is determined by a rapid human population growth, poor law enforcement, political instability, poverty, poor infrastructure embedded in a complex set of ancient traditions, culture and social interactions. Conservationists have to recognize that aside from environmental considerations, it is essential to take the interest and needs of resource users and of the management associations itself into account to preserve these unique ecosystems, for their biodiversity but also for the local people.

References

Abell, R. 2002. Conservation biology for the biodiversity crisis: a freshwater follow-up. *Conservation Biology* 16, 5: 1435–1437.

Abrams, R. W., Anwana, E. D., Ormsby, A., Dovie, D. B., Ajagbe, A. et al. 2009. Integrating top-down with bottom-up conservation policy in Africa. *Conservation Biology* 23, 4: 799–804.

Adams, W. M., Aveling, R., Brockington, D., Dickson, B., Elliott, J. et al. 2004. Biodiversity conservation and the eradication of poverty. *Science* 306, 5699: 1146–1149.

Agrawal, A. 2001. Common property institutions and sustainable governance of resources. *World development* 29, 10: 1649–1672.

Aguiñaga, E., Henriques, I., Scheel, C. and Scheel, A. 2018. Building resilience: a self-sustainable community approach to the triple bottom line. *Journal of Cleaner Production* 173, 186–196.

Albright, T. P., Moorhouse, T. G. and McNabb, T. J. 2004. The rise and fall of water hyacinth in Lake Victoria and the Kagera River Basin, 1989–2001. *Journal of Aquatic Plant Management* 42: 73–84.

Aloo, P. A., Ojwang, W. O., Omondi, R., Njiru, J. M. and Oyugi, D. O. 2013. A review of the impacts of invasive aquatic weeds on the biodiversity of some tropical water bodies with special reference to Lake Victoria (Kenya). *Biodiversity Journal* 4, 4: 471–482.

Andrade, G. S. and Rhodes, J. R. 2012. Protected areas and local communities: an inevitable partnership toward successful conservation strategies? *Ecology and Society* 17, 4: 1–14.

Andrianandrasana, H. T., Randriamahefasoa, J., Durbin, J., Lewis, R. E. and Ratsimbazafy, J. H. 2005. Participatory ecological monitoring of the Alaotra wetlands in Madagascar. *Biodiversity and Conservation* 14, 11: 2757–2774.

Baillie, J.E.M. and Butcher, E. R. 2012. Priceless or worthless? The world's most threatened species. *Zoological Society of London, United Kingdom*. 63 pp.

Bakoariniaina, L. N., Kusky, T. and Raharimahefa, T. 2006. Disappearing Lake Alaotra: Monitoring catastrophic erosion, waterway silting, and land degradation hazards in Madagascar using Landsat imagery. *Journal of African Earth Sciences* 44, 2: 241–252.

Bamford, A, J., Sam, T. S., Razafindrajao, F., Robson, H. Woolaver, L. G. et al. 2015. The status and ecology of the last wild population of Madagascar Pochard *Aythya innotata*. *Bird Conservation International* 25, 97–110.

Bamford, A. J., Razafindrajao, F., Young, R. P. and Hilton, G. M. 2017. Profound and pervasive degradation of Madagascar's freshwater wetlands and links with biodiversity. *PloS ONE* 12, 8: e0182673.

Barber, P. H., Ablan-Lagman, M. C. A., Berlinck, R. G., Cahyani, D., Crandall, E. D. et al. 2014. Advancing biodiversity research in developing countries: the need for changing paradigms. *Bulletin of Marine Science* 90, 1: 187–210.

Barling, R. D. and Moore, I. D. 1994. Role of buffer strips in management of waterway pollution: a review. *Environmental Management* 18, 4: 543–558.

Barnes, M. D., Craigie, I. D., Harrison, L. B., Geldmann, J., Collen, B. et al. 2016. Wildlife population trends in protected areas predicted by national socio-economic metrics and body size. *Nature Communications* 7, 12747.

Barnosky, A. D., Matzke, N., Tomiya, S., Wogan, G. O., Swartz, B. et al. 2011. Has the earth's sixth mass extinction already arrived? *Nature* 471, 7336: 51.

Barrett, C. B., Brandon, K., Gibson, C. and Gjertsen, H. 2001. Conserving tropical biodiversity amid weak institutions. *BioScience* 51, 6: 497–502.

Bellemare, M. F. 2009. Sharecropping, insecure land rights and land titling policies: a case study of Lac Alaotra, Madagascar. *Development Policy Review* 27, 1: 87–106.

Benstead, J. P., De Rham, P. H., Gattolliat, J. L., Gibon, F. M., Loiselle, P. V. et al. 2003. Conserving Madagascar's freshwater biodiversity. *AIBS Bulletin* 53, 11: 1101–1111.

Bethune, S. and Roberts, K. 2002. Aquatic weeds and their control. In: *Defining and mainstreaming environmental sustainability in water resources management in southern Africa*. R. Hirji, P. Johnson, P. Maro and T. Matiza Chiuta (eds.), pp 205–236. SADC, IUCN, SARDC, World Bank, Harare and Washington, DC.

Binns, T., Dixon, A. and Nel, E. 2012. *Africa: diversity and development*. Routledge, London. 432 pp.

Blaikie, P. 2006. Is small really beautiful? Community-based natural resource management in Malawi and Botswana. *World Development* 34, 11: 1942–1957.

Bodin, Ö., Tengö, M., Norman, A., Lundberg, J. and Elmqvist, T. 2006. The value of small size: loss of forest patches and ecological thresholds in southern Madagascar. *Ecological Applications* 16, 2: 440–451.

Borgerson, C., McKean, M. A., Sutherland, M. R. and Godfrey, L. R. 2016. Who hunts lemurs and why they hunt them. *Biological Conservation* 197, 124–130.

Borgerson, C., Vonona, M. A., Vonona, T., Anjaranirina, E. J. G., Lewis, R. et al. 2018. An evaluation of the interactions among household economies, human health, and wildlife hunting in the Lac Alaotra wetland complex of Madagascar. *Madagascar Conservation and Development* 13, 1: 1–9.

Brendonck, L., Maes, J., Rommens, W., Dekeza, N., Nhiwatiwa, T. 2003. The impact of water hyacinth (*Eichhornia crassipes*) in a eutrophic subtropical impoundment (Lake Chivero, Zimbabwe). II. Species diversity. *Archiv für Hydrobiologie* 158, 3: 389–405.

Breuil, C. and Grima, D. 2014. Baseline report Madagascar. *SmartFish programme of the Indian Ocean Commission, Fisheries Management FAO component*, Ebene, Mauritius. 35 pp.

Brooks, T. M., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., Rylands, A. B. et al. 2002. Habitat loss and extinction in the hotspots of biodiversity. *Conservation Biology* 16, 4: 909–923.

Brooks, J., Waylen, K. and Mulder, M. 2013. Assessing community-based conservation projects: a systematic review and multilevel analysis of attitudinal, behavioral, ecological, and economic outcomes. *Environmental Evidence* 2, 1: 2.

Brown, J. H. 2014. Why are there so many species in the tropics? *Journal of Biogeography* 41, 1: 8–22.

Bruelle, G. 2014. Pertinence de l'agriculture de conservation pour tamponner les aléas climatiques : cas des systémes de culture en riz pluvial au Lac Alaotra, Madagascar [dissertation]. Ecology, environment. *Université d'Antananarivo, Montpellier SupAgro*. 110 pp.

Bruelle, G., Naudin, K., Scopel, E., Domas, R., Rabeharisoa, L. et al. 2014. Short-to mid-term impact of conservation agriculture on yield variability of upland rice: evidence from farmer's fields in Madagascar. *Experimental Agriculture* 51, 1: 66–84.

Butchart, S. H., Walpole, M., Collen, B., Van Strien, A., Scharlemann, J. P. et al. 2010. Global biodiversity: indicators of recent declines. *Science* 328, 5982: 1164 – 1168.

Canonico, G. C., Arthington, A., McCrary, J. K. and Thieme, M. L. 2005. The effects of introduced tilapias on native biodiversity. *Aquatic Conservation: Marine and Freshwater Ecosystems* 15, 5: 463–483.

Carpenter, S. R., Stanley, E. H. and Vander Zanden, M. J. 2011. State of the world's freshwater ecosystems: physical, chemical, and biological changes. *Annual Review of Environment and Resources*, 36, 75–99.

Ceballos, G., Ehrlich, P. R., Barnosky, A. D., García, A., Pringle, R. M. et al. 2015. Accelerated modern human–induced species losses: entering the sixth mass extinction. *Science Advances* 1, 5: e1400253.

Ceballos, G., Ehrlich, P. R. and Dirzo, R. 2017. Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. *Proceedings of the National Academy of Sciences* 114, 30: E6089–E6096.

Chape, S., Spalding, M., Taylor, M., Putney, A., Ishwaran, N. et al. 2008. History, definitions, values and global perspective. In: *The world's protected areas. Status, Values and Prospects in the 21st Century*. S. Chape, M. Spalding, and M. D. Jenkins (eds.), pp 1–35. UNEP World Conservation Monitoring Centre. University of California Press, Berkeley, USA.

Chaperon, P., Danloux, J. and Ferry, L. 1993. Fleuves et rivières de Madagascar. *Collection Monographie Hydrologique no.10*, ORSTOM, Paris, France. 877 pp.

Cinner, J. E. 2010. Poverty and the use of destructive fishing gear near east African marine protected areas. *Environmental Conservation* 36, 4: 321–326.

Clark, M. 2012. Deforestation in Madagascar: consequences of population growth and unsustainable agricultural processes. *Global Majority E-Journal* 3, 1: 61–71.

Coetzee, J. A., Jones, R. W. and Hill, M. P. 2014. Water hyacinth, *Eichhornia crassipes* (Pontederiaceae), reduces benthic macroinvertebrate diversity in a protected subtropical lake in South Africa. *Biodiversity and Conservation* 23, 5: 1319–1330.

Conservation International 2011. Biodiversity hotspots revisited. Vector digital data. Conservation Synthesis, C*enter for Applied Biodiversity Science at Conservation International*, Arlington. https://databasin.org/datasets/23fb5da1586141109fa6f8d45de0a260. April 5, 2018.

Copsey, J. A., Jones, J. P., Andrianandrasana, H., Rajaonarison, L. H. and Fa, J. E. 2009a. Burning to fish: local explanations for wetland burning in Lac Alaotra, Madagascar. *Oryx* 43, 3: 403–406.

Copsey, J. A., Rajaonarison, L. H., Randriamihamina, R. and Rakotoniaina, L. J. 2009b. Voices from the marsh: livelihood concerns of fishers and rice cultivators in the Alaotra wetland. *Madagascar Conservation and Development* 4, 1: 25–30.

Cowling, R. M. and Bond, W. J. 1991. How small can reserves be? An empirical approach in Cape Fynbos, South Africa. *Biological Conservation* 58, 3: 243–256.

Czech, B. 2008. Prospects for reconciling the conflict between economic growth and biodiversity conservation with technological progress. *Conservation Biology* 22, 6: 1389–1398.

Daily, G. C. 2000. Management objectives for the protection of ecosystem services. *Environmental Science and Policy* 3, 6: 333–339.

Davidson, N. C. 2014. How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research* 65, 10: 934–941.

De Groot, R. S. 1987. Environmental functions as a unifying concept for ecology and economics. *Environmentalist* 7, 2: 105–109.

Ducrot, R. and Capillon, A. 2004. A practice analysis to account for adoption of innovations in irrigated rice cropping systems in Lake Alaotra (Madagascar). *Journal of Sustainable Agriculture* 24, 3: 71–96.

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z. I., Knowler, D. J. et al. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Reviews* 81, 2: 163–182.

Duffy, R. 2005. Global environmental governance and the challenge of shadow states: the impact of illicit sapphire mining in Madagascar. *Development and Change* 36, 5: 825–843.

Durbin, J., Funk, S. M., Hawkins, F., Hills, D. M., Jenkins, P. D. et al. 2010 Investigations into the status of a new taxon of *Salanoia* (Mammalia: Carnivora: Eupleridae) from the marshes of Lac Alaotra, Madagascar. *Systematics and Biodiversity* 8:3, 341–355.

Eckerberg, K., Bjärstig, T. and Zachrisson, A. 2015. Incentives for collaborative governance: top-down and bottom-up initiatives in the Swedish Mountain region. *Mountain Research and Development* 35, 3: 289–298.

Elvidge, C. D., Sutton, P. C., Ghosh, T., Tuttle, B. T., Baugh, K. E. et al 2009. A global poverty map derived from satellite data. *Computers and Geosciences* 35, 8: 1652–1660.

Fa, J. E., Currie, D. and Meeuwig, J. 2003. Bushmeat and food security in the Congo Basin: linkages between wildlife and people's future. *Environmental Conservation* 30, 1: 71–78.

Fabricius, C. 2004. The fundamentals of community-based natural resource management. In: *Rights, resources and rural development: Community-based natural resource management in southern Africa*. C. Fabricius, E. Koch, H. Magome and S. Turner (eds.), pp 3–43. Routledge, London and Sterling.

Fabricius, C. and Collins, S. 2007. Community-based natural resource management: governing the commons. *Water Policy* 9, Suppl. 2: 83–97.

FAO 2016. The state of world fisheries and aquaculture. Contributing to food security and nutrition for all. *Food and Agriculture Organization of the United Nations*, Rome. 200 pp.

FAO. 2017. Status of inland fisheries in Africa, CIFAA/XVII/2017/4. *FAO Fisheries and Aquaculture Department, Committee on inland fisheries and aquaculture of Africa*, Gambia. 12 pp.

Ferraro, P. J., Hanauer, M. M. and Sims, K. R. 2011. Conditions associated with protected area success in conservation and poverty reduction. *Proceedings of the National Academy of Sciences* 108, 34: 13913–13918.

Ferry, L., Mietton, M., Robison, L. and Erismann, J. 2009. Alaotra Lake (Madagascar) – past, present and future. *Annals of Geomorphology* 53, 3: 299–318.

Finlayson, C. M., Davidson, N. C., Spiers, A. G. and Stevenson, N. J. 1999. Global wetland inventory – current status and future priorities. *Marine and Freshwater Research* 50, 8: 717–727.

Fisher, B. and Christopher, T. 2007. Poverty and biodiversity: measuring the overlap of human poverty and the biodiversity hotspots. *Ecological Economics* 62, 1: 93–101.

Fosu, A. K. 2017. Growth, inequality, and poverty reduction in developing countries: recent global evidence. *Research in Economics* 71, 2: 306–336.

Fraser, D. J., Coon, T., Prince, M. R., Dion, R. and Bernatchez, L. 2006a. Integrating traditional and evolutionary knowledge in biodiversity conservation: a population level case study. *Ecology and Society* 11, 2: 4.

Fraser, E. D., Dougill, A. J., Mabee, W. E., Reed, M. and Mc Alpine, P. 2006b. Bottom up and top down: analysis of participatory processes for sustainability indicator identification as a pathway to community empowerment and sustainable environmental management. *Journal of environmental Management*, 78, 2: 114–127.

Freebairn, D. M. and King, C. A. 2003. Reflections on collectively working toward sustainability: indicators for indicators! *Australian Journal of Experimental Agriculture* 43, 3: 223–238.

Fritz-Vietta, N. V., Röttger, C. and Stoll-Kleemann, S. 2009. Community-based management in two biosphere reserves in Madagascar–distinctions and similarities: what can be learned from different approaches? *Madagascar Conservation and Development* 4, 2: 86–97.

Fritz-Vietta, N. V. M., Ferguson, H. B., Stoll-Kleemann, S. and Ganzhorn, J. U. 2011. Conservation in a biodiversity hotspot: insights from cultural and community perspectives in Madagascar. In: *Biodiversity hotspots: Distribution and protection of* *conservation priority areas*. F. E. Zachos and J. C. Habel (eds.). pp. 209–233. Springer, Berlin.

Froger, G. and Méral, P. 2012. Towards an institutional and historical analysis of environmental policy in Madagascar. *Environmental Policy and Governance* 22, 5: 369–380.

Fu, B., Wang, K., Lu, Y., Liu, S., Ma, K., Chen, L. and Liu, G. 2004. Entangling the complexity of protected area management: the case of Wolong Biosphere Reserve, southwestern China. *Environmental Management* 33, 6: 788–798.

Ganzhorn, J. U., Lowry, P. P., Schatz, G. E. and Sommer, S. 2001. The biodiversity of Madagascar: one of the world's hottest hotspots on its way out. *Oryx* 35 4: 346–348.

Gardner, C. J., Nicoll, M. E., Birkinshaw, C., Harris, A., Lewis, R. E. et al. 2018. The rapid expansion of Madagascar's protected area system. *Biological Conservation* 220, 29–36.

Gettys, L. A., Haller, W. T. and Bellaud, M. 2014. *Biology and control of aquatic plants. A best management practices handbook*, 3rd edition. Aquatic Ecosystem Restoration Foundation, Marietta, GA. 209 pp.

Giam, X., Bradshaw, C. J., Tan, H. T. and Sodhi, N. S. 2010. Future habitat loss and the conservation of plant biodiversity. *Biological Conservation* 143, 7: 1594–1602.

Gibbs, J. P. 2000. Wetland loss and biodiversity conservation. *Conservation Biology* 14, 1: 314–317.

Gibson, J. F., Stein, E. D., Baird, D. J., Finlayson, C. M., Zhang, X. et al. 2015. Wetland ecogenomics–the next generation of wetland biodiversity and functional assessment. *Wetland Science and Practice* 32, 27–32.

Gichuki, J., Guebas, F. D., Mugo, J., Rabuor, C. O., Triest, L. et al. 2001. Species inventory and the local uses of the plants and fishes of the Lower Sondu Miriu wetland of Lake Victoria, Kenya. *Hydrobiologia* 458, 1–3: 99–106.

Goodman, S. M. and Benstead, J. P. 2005. Updated estimates of biotic diversity and endemism for Madagascar. *Oryx* 39, 1: 73–77.

Götmark, F. and Thorell, M. 2003. Size of nature reserves: densities of large trees and dead wood indicate high value of small conservation forests in southern Sweden. *Biodiversity and Conservation* 12, 6: 1271–1285.

Gore, M. L., Ratsimbazafy, J., Rajaonson, A., Lewis, A. and Kahler, J. S. 2016. Public perceptions of poaching risks in a biodiversity hotspot: implications for wildlife trafficking interventions. *Journal of Trafficking, Organized Crime and Security* 2, 1–20.

Guillera-Arroita, G., Lahoz-Monfort, J. J., Milner-Gulland, E. J., Young, R. P. and Nicholson, E. 2010. Monitoring and conservation of the critically endangered Alaotran gentle lemur *Hapalemur alaotrensis*. *Madagascar Conservation and Development* 5, 2: 103–109.

Gunnarsson, C. C. and Petersen, C. M. 2007. Water hyacinths as a resource in agriculture and energy production: a literature review. *Waste Management* 27, 1: 117–129.

Hannigan, J. 2006. *Environmental sociology*, 2nd edition. Routledge, Abingdon, Oxon. 194 pp.

Hanspach, J., Abson, D. J., French Collier, N., Dorresteijn, I., Schultner, J. et al. 2017. From trade-offs to synergies in food security and biodiversity conservation. *Frontiers in Ecology and the Environment* 15, 9: 489–494.

Harper, D. M., Harper, M. M., Virani, M. A., Smart, A., Childress, R. B. et al. 2002. Population fluctuations and their causes in the African fish eagle (*Haliaeetus vocifer* (Daudin)) at Lake Naivasha, Kenya. *Hydrobiologia* 488: 171 –180.

Harper, G. J., Steininger, M. K., Tucker, C. J., Juhn, D. and Hawkins, F. 2007. Fifty years of deforestation and forest fragmentation in Madagascar. *Environmental Conservation* 34, 4: 325–333.

Harvey, C.A., Rakotobe, Z. L., Rao, N. S., Dave, R., Razafimahatratra, H. et al. 2014. Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar. *Philosophical Transactions of the Royal Society B* 369: 20130089.

Herrera, J. P. 2017. Prioritizing protected areas in Madagascar for lemur diversity using a multidimensional perspective. *Biological Conservation* 207, 1–8.

Hewitson, B. 2015. To build capacity, build confidence. *Nature Geoscience* 8, 7: 497.

Hockings, M., Stolton, S., Leverington, F., Dudley, N. and Courrau, J. 2006. Evaluating effectiveness: a framework for assessing management effectiveness of protected areas. 2nd edition. *IUCN*, Gland, Cambridge, UK. 105 pp.

Holland, R. A., Darwall, W. R. T. and Smith, K. G. 2012. Conservation priorities for freshwater biodiversity: the key biodiversity area approach refined and tested for continental Africa. *Biological Conservation* 148, 1: 167–179.

Howard, G. W. and Harley, K. L. S. 1997. How do floating aquatic weeds affect wetland conservation and development? How can these effects be minimised? *Wetlands Ecology and Management* 5, 3: 215–225.

Huff, A. R. 2014. Weathering the 'Long wounded year': livelihoods, nutrition, and changing political ecologies in the Mikea Forest region, Madagascar. *Journal of Political Ecology* 21, 84.

IPCC 2014. Summary for policymakers. In: *Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the fifth assessment report of the ntergovernmental Panel on Climate Change.* Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea et al. (eds.), pp. 1–32. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IUCN 2004. Red List assessment of Madagascar's freshwater fishes. *IUCN*, Gland, Switzerland. 218 pp.

Jarosz, L. 1991. Women as rice sharecroppers in Madagascar. *Society and Natural Resources* 4, 1: 53–63.

Junk, W. J. 2002. Long-term environmental trends and the future of tropical wetlands. *Environmental Conservation* 29, 4: 414–435.

Junk, W. J., An, S., Finlayson, C. M., Gopal, B., Květ, J. et al 2013. Current state of knowledge regarding the world's wetlands and their future under global climate change: a synthesis. *Aquatic Sciences* 75, 1: 151–167.

Karimi, A., Tulloch, A. I., Brown, G. and Hockings, M. 2017. Understanding the effects of different social data on selecting priority conservation areas. *Conservation Biology* 31, 6: 1439–1449.

Keane, A., Jones, J. P., Edwards-Jones, G. and Milner-Gulland, E. J. 2008. The sleeping policeman: understanding issues of enforcement and compliance in conservation. *Animal Conservation* 11, 2: 75–82.

Kateregga, E. and Sterner, T. 2007. Indicators for an invasive species: water hyacinths in Lake Victoria. *Ecological Indicators* 7, 2: 362–370.

Kaufman, S. R. 2012. A comparison study of a bird population in Lake Alaotra: The effects of a protected area. *Independent Study Project (ISP) Collection*. Paper 1469. http://digitalcollections.sit.edu/isp_collection/1469. March 21, 2018.

Keddy, P. A. 2010. *Wetland ecology: principles and conservation.* Cambridge University Press. 514 pp.

Keller, E. 2009. The danger of misunderstanding 'culture'. *Madagascar Conservation and Development* 4, 2. 82–85.

Kerschner, C. 2010. Economic de-growth vs. steady-state economy. *Journal of Cleaner Production* 18, 6: 544–551.

Klein, C. J., Chan, A., Kircher, L., Cundiff, A. J., Gardner, N. et al 2008. Striking a balance between biodiversity conservation and socioeconomic viability in the design of marine protected areas. *Conservation Biology* 22, 3: 691–700.

Koutika, L. S. and Rainey, H. J. 2015. A review of the invasive, biological and beneficial characteristics of aquatic species *Eichhornia crassipes* and *Salvinia molesta*. *Applied Ecology and Environmental Research* 13, 1: 263–275.

Kull, C. A. 2002. Empowering pyromaniacs in Madagascar: ideology and legitimacy in community-based natural resource management. *Development and Change* 33, 1: 57–78.

Kull, C. A. 2012. Air photo evidence of historical land cover change in the highlands: wetlands and grasslands give way to crops and woodlots. *Madagascar Conservation and Development* 7, 3: 144–152.

Langan, C., Farmer, J., Rivington, M. and Smith, J. U. 2018. Tropical wetland ecosystem service assessments in East Africa; A review of approaches and challenges. *Environmental Modelling and Software* 102, 260–273.

Larson, B., Minten, L. and Razafindralambo, R. 2006. Unravelling the linkages between the millennium development goals for poverty, education, access to water and household water use in developing countries: evidence from Madagascar, *The Journal of Development Studies* 42:1, 22–40.

Laurance, W. F., Sayer, J. and Cassman, K. G. 2014. Agricultural expansion and its impacts on tropical nature. *Trends in Ecology and Evolution* 29, 2: 107–116.

Leverington, F., Costa, K. L., Pavese, H., Lisle, A. and Hockings, M. 2010. A global analysis of protected area management effectiveness. *Environmental Management* 46, 5: 685–698.

Lund, J. F. and Saito-Jensen, M. 2013. Revisiting the issue of elite capture of participatory initiatives. *World Development* 46, 104–112.

Luque G. M., Bellard C., Bertelsmeier C., Bonnaud E., Genovesi P. et al. 2013. Monster fern makes IUCN invader list. *Nature* 498: 37.

Lynch, A. J., Cowx, I. G., Fluet-Chouinard, E., Glaser, S. M., Phang, S. C. 2017. Inland fisheries – Invisible but integral to the UN Sustainable Development Agenda for ending poverty by 2030. *Global Environmental Change* 47, 167–173.

Maes, J., Teller, A., Erhard, M., Murphy, P., Paracchini, M. L. et al. 2014. Mapping and assessment of ecosystems and their services: indicators for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020. *European Union Technical Report; No. 2014-080*. Publications Office of the European Union, Luxembourg. 81 pp.

Mac Dowall, C., Penot, E. and David, C. 2011. Impact of CA adoption conservation agriculture on farming systems in the region of Lake Alaotra, Madagascar. *CA2AFRICA Peoject*, Working document Madagascar. 66 pp.

Máiz-Tomé, L., Sayer, C. and Darwall, W. 2018. The status and distribution of freshwater biodiversity in Madagascar and the Indian Ocean islands hotspot. *IUCN*, Gland, Switzerland. 140 pp.

Malik, A. 2007. Environmental challenge vis a vis opportunity: the case of water hyacinth. *Environment International* 33, 1: 122–138.

Mander, Ü., Helming, K. and Wiggering H. 2007. Multifunctional land use: meeting future demands for landscape goods and services. In: *Multifunctional Land Use*. Ü. Mander, Wiggering, H., Helming K. (eds), pp 1–13. Springer, Berlin and Heidelberg

Mbiti, I. M. 2016. The need for accountability in education in developing countries. *Journal of Economic Perspectives* 30, 3: 109–32.

McCartney, M., Rebelo, L-M., Senaratna Sellamuttu, S. and de Silva, S. 2010. Wetlands, agriculture and poverty reduction. *IWMI ResearchReport 137*, International Water Management Institute, Colombo, Sri Lanka. 39 pp.

McClanahan, T. R., Maina, J. and Davies, J. 2005. Perceptions of resource users and managers towards fisheries management options in Kenyan coral reefs. *Fisheries Management and Ecology* 12, 2: 105–112.

Measham, T. G. and Lumbasi, J. A. 2013. Success factors for community-based natural resource management (CBNRM): lessons from Kenya and Australia. *Environmental Management* 52, 3: 649–659.

Mietton, M., Gunnell, Y., Nicoud, G., Ferry, L., Razafimahefa, R. et al. 2018. 'Lake'Alaotra, Madagascar: a late quaternary wetland regulated by the tectonic regime. *CATENA* 165, 22–41.

Mitsch, W. J., and J. G. Gosselink. 2015. *Wetlands*. 5th edition. John Wiley and Sons, New Jersey, USA. 736 pp.

Mittermeier, R. A., Turner, W. R., Larsen, F. W., Brooks, T. M. and Gascon C. 2011. Global biodiversity conservation: the critical role of hotspots. In: *Biodiversity hotspots:*

distribution and protection of conservation priority areas. F. E. Zachos, J. C. Habel (eds.), pp 3–22. Springer, Heidelberg.

Mogaka, H., Gichere, S., Davis, J. R. and R. Hirji. 2005. Climate variability and water resources degradation in Kenya: improving water resources development and management. *World Bank Working Paper No. 69*, Washington, DC. 130 pp.

Molotoks, A., Kuhnert, M., Dawson, T. P. and Smith, P. 2017. Global hotspots of conflict risk between food security and biodiversity conservation. *Land* 6, 4: 67.

Moreau J. 1979/80. Le lac Alaotra à Madagascar: cinquante ans d'aménagement des pêches. *Cahier ORSTOM. Hydrobiologie* 3–4: 171–179.

Mutschler, T., Feistner, A. T. C. and Nievergelt, C. M. 1998. Preliminary field data on group size, diet and activity in the Alaotran gentle lemur *Hapalemur griseus alaotrensis*. *Folia Primatologica* 69, 5: 325–330.

Mutschler, T. 2003. Lake Alaotra. In: *The natural history of Madagascar*. S. M. Goodman and J. P. Benstead (eds.), pp 1530–1534. University of Chicago Press, Chicago.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A. and Kent, J. 2000. Biodiversity hotspots for conservation priorities. *Nature* 403, 6772: 853.

Naidoo, R., Balmford, A., Ferraro, P. J., Polasky, S., Ricketts, T. H. et al. 2006. Integrating economic costs into conservation planning. *Trends in Ecology and Evolution* 21, 12: 681–687.

Nellemann, C., Henriksen, R., Raxter, P., Ash, N., Mrema, E. 2014. The environmental crime crisis – threats to sustainable development from illegal exploitation and trade in wildlife and forest resources. A UNEP rapid response assessment. *United Nations Environment Programme and GRID-Arendal*, Nairobi and Arendal. 108 pp.

Neugarten, R. A., Honzák, M., Carret, P., Koenig, K., Andriamaro, L. et al. 2016. Rapid assessment of ecosystem service co-benefits of biodiversity priority areas in Madagascar. *PloS ONE* 11, 12: e0168575.

Njuguna, S. G. 1992. Floating aquatic weeds in Kenya. In: *Wetlands of Kenya*. S. A. Crafter, S.G. Njuguna and G. W. Howard (eds.), pp. 85–90. IUCN, Gland, Switzerland

Otiang'a-Owiti, G. E. and Oswe, I. A. 2007. Human impact on lake ecosystems: the case of Lake Naivasha, Kenya. *African Journal of Aquatic Science* 32, 1: 79–88.

Patel, S. 2012. Threats, management and envisaged utilizations of aquatic weed *Eichhornia crassipes*: an overview. *Reviews in Environmental Science and Biotechnology* 11, 3: 249–259.

Penot, É., Dabat, M. H., Rakotoarimanana, A. and Grandjean, P. 2014. L'évolution des pratiques agricoles au lac Alaotra à Madagascar. Une approche par les temporalités. *Biotechnologie, Agronomie, Société et Environnement* 18, 3: 329.

Pidgeon M. 1996. An ecological survey of Lake Alaotra and selected wetlands of central and eastern Madagascar in analyzing the demise of Madagascar pochard *Aythya innotata*. Antananarivo, *WWF/Missouri Botanical Garden*. 139 pp.

Pietrzyk-Kaszyńska, A. and Grodzińska-Jurczak, M. 2015. Bottom-up perspectives on nature conservation systems: the differences between regional and local administrations. *Environmental Science and Policy* 48, 20–31.

Pievani, T. 2014. The sixth mass extinction: anthropocene and the human impact on biodiversity. *Rendiconti Lincei* 25, 1: 85–93.

Platteau, J. P. 2004. Monitoring elite capture in community-driven development. *Development and Change* 35, 2: 223–246.

Pollini, J. 2011. The difficult reconciliation of conservation and development objectives: the case of the Malagasy Environmental Action Plan. *Human Organization* 70, 1: 74–84.

Pollini, J., Hockley, N. and Muttenzer, F. D. 2014. The transfer of natural resource management rights to local communities. In: *Conservation and environmental management in Madagascar*. I. R. Scales (ed.), pp. 172–192. Routledge, Oxon and New York.

Pollini, J. and Lassoie, J. P. 2011. Trapping farmer communities within global environmental regimes: the case of the GELOSE legislation in Madagascar. *Society and Natural Resources* 24, 8: 814–830.

Pretty, J. N. 1995. Participatory learning for sustainable agriculture. *World development* 23, 8: 1247–1263.

Rabarison, H., Randriamahaleo, S. I., Andriambelo, F. M., Randrianasolo H. L. 2015. National biodiversity and action plans 2015–2025. *Ministère de l'environnement, de l'écologie, de la mer et des forêts*. Antananarivo, Madagascar.

Rakotoarisoa, T. F., Waeber, P. O., Richter, T. and Mantilla Contreras, J. 2015. Water hyacinth (*Eichhornia crassipes*), any opportunities for the Alaotra wetlands and livelihoods? *Madagascar Conservation and Development* 10, 3:128–136.

Rakotoarisoa, T. F. 2018. Use of water hyacinth (*Eichhornia crassipes*) in poor and remote regions – a case study from Lake Alaotra, Madagascar [dissertation]. *University of Hildesheim*. 142 pp.

Rakotomanana, H., Jenkins, R. K. and Ratsimbazafy, J. 2013. Conservation challenges for Madagascar in the next decade. In: *Conservation biology: voices from the tropics.* N. S. Sodhi, L. Gibson and P. H. Raven (eds.), pp 33–39. John Wiley and Sons, New Jersey.

Ralainasolo, F. B., Waeber, P.O., Ratsimbazafy, J., Durbin, J. Lewis, R. 2006. The Alaotra gentle lemur: Population estimation and subsequent implications. *Madagascar Conservation and Development* 1, 1: 9–10.

Ramanampamonjy, J. R., Rasoamampionona Raminosoa, N., Andrianandrasana, H.T., Wilmé, L., Durbin, J. et al. 2003. Information sheet on Ramsar Wetlands (RIS): Lake Alaotra wetlands and catchment basin. *Durrell Wildlife Conservation Trust Madagascar, Antananarivo*. 12 pp.

Ramsar 2018. *Ramsar sites information service. Annotated list of wetlands of international importance*. https://www.ramsar.org/sites/default/files/documents/library/sitelist.pdf March 16, 2018.

Ratsimbazafy, J. H., Ralainasolo, F. B., Rendigs, A., Mantilla-Contreras, J., Andrianandrasana, H. et al. 2013. Gone in a puff of smoke? *Hapalemur alaotrensis* at great risk of extinction. *Lemur News* 17: 14–18.

Razafindrajao, F., Bamford, A. J., Young, H. G., Andrianarimisa, A., Aboudou, A. I. B. et al. 2017. Reassessing the conservation outlook for Madagascar's endemic Anatidae following the creation of new protected areas. *Wildfowl* 67, 67: 72–86.

Razafindraibe, M., Kuhlman, A. R., Rabarison, H., Rakotoarimanana, V., Rajeriarison, Ch. et al. 2013. Medicinal plants used by women from Agnalazaha littoral forest (southeastern Madagascar). *Journal of Ethnobiology and Ethnomedicine* 9 73: 1–13.

Razanadrakoto, D. R. and Rafaliarison, J. 2005. Délimitation des zones de frai dans le lac Alaotra. *Durrell Wildlife Conservation Trust*, Antananarivo. 45 pp.

Rebelo, L. M., McCartney, M. P. and Finlayson, C. M. 2010. Wetlands of Sub-Saharan Africa: distribution and contribution of agriculture to livelihoods. *Wetlands Ecology and Management* 18, 5: 557–572.

Regos, A., Hermoso, V., D'Amen, M., Guisan, A. and Brotons, L. 2018. Trade-offs and synergies between bird conservation and wildfire suppression in the face of global change. *Journal of Applied Ecology*, 55, 5: 2181–2192.

Reinthal, P. N. and Stiassny, M. L. J. 1991. The freshwater fishes of Madagascar: a study of an endangered fauna with recommendations for a conservation strategy. *Conservation Biology* 5, 2: 231–243.

Resosudarmo, I. A. P. 2004. Closer to people and trees: will decentralisation work for the people and the forests of Indonesia? *The European Journal of Development Research* 16, 1: 110–132.

Reuter, K. E., La Fleur, M. and Clarke, T. A. 2017. Endangered species: illegal lemur trade grows in Madagascar. *Nature 541* 7636: 157.

Richter, T., Rendigs, A. and Maminirina, C. P. 2015. Conservation messages in speech bubbles – evaluation of an environmental education comic distributed in elementary echools in Madagascar. *Sustainability* 7, 7: 8855–8880.

Riquier, J. ans Ségalen, P. 1949. Notice sur la carte pédologique du lac Alaotra. Mémoires de l'Institut Scientifique de Madagascar. *Série D: Sciences de la Terre* 1, 1: 1–31.

Roe, D. 2008. The origins and evolution of the conservation-poverty debate: a review of key literature, events and policy processes. *Oryx* 42, 4: 491–503.

Saint-André, F., Dugué, P., Penot, E. and Le Gal, P. Y. 2010. Analyse des relations agriculture-élevage et place des techniques d'agriculture de conservation au sein d'exploitations du lac Alaotra (Madagascar): *projet ANR PEPITES,* rapport d'étude. http://agritrop.cirad.fr/556542/. March 20, 2018.

Saito-Jensen, M., Nathan, I. and Treue, T. 2010. Beyond elite capture? Community-based natural resource management and power in Mohammed Nagar village, Andhra Pradesh, India. *Environmental Conservation* 37, 3: 327–335.

Sala, O. E., Chapin, F. S., Armesto, J. J., Berlow, E., Bloomfield, J. et al. 2000. Global biodiversity scenarios for the year 2100. *Science* 287, 5459: 1770–1774.

Sanderson, S. E. and Redford, K. H. 2003. Contested relationships between biodiversity conservation and poverty alleviation. *Oryx* 37, 4: 389–390.

Schuyt, K. D. 2005. Economic consequences of wetland degradation for local populations in Africa. *Ecological Economics* 53, 2: 177–190.

Schwitzer, C., Mittermeier, R. A., Johnson, S. E., Donati, G., Irwin, M. et al. 2014. Averting lemur extinctions amid Madagascar's political crisis. *Science* 343, 6173: 842–843.

Schwitzer, C., Mittermeier, R. A., Rylands, A. B., Chiozza, F., Williamson, E. A. et al. 2017. Primates in Peril: The world's 25 most endangered primates 2016–2018. *IUCN SSC Primate Specialist Group (PSG), International Primatological Society (IPS), Conservation International (CI), and Bristol Zoological Society*, Arlington, VA. 99 pp.

Shadie, P. and Epps, M. 2008. Securing protected areas in the face of global change: key lessons learned from case studies and field learning sites in protected areas. *IUCN Asia Regional Office*, Bangkok, Thailand. 49 pp.

Smith, B. D. and Zeder, M. A. 2013. The onset of the Anthropocene. *Anthropocene* 4, 8–13.

Snel, M. 2004. Poverty-conservation mapping applications. *Proceedings of the 3rd IUCN World Conservation Congress*, Bangkok, Thailand. 19 pp.

Sodhi, N. S., Butler, R. and Raven, P. H. 2011. Bottom-up conservation. *Biotropica* 43, 5: 521–523.

Strayer, D. L. and Dudgeon, D. 2010. Freshwater biodiversity conservation: recent progress and future challenges. *Journal of the North American Benthological Society* 29, 1: 344–358.

Theisinger, O. and Ratianarivo, M. C. 2015. Patterns of reptile diversity loss in response to degradation in the spiny forest of southern Madagascar. *Herpetological Conservation and Biology* 10, 1: 273–283.

Tscharntke, T., Clough, Y., Wanger, T. C., Jackson, L., Motzke, I. et al. 2012. Global food security, biodiversity conservation and the future of agricultural intensification. *Biological Conservation* 151, 1: 53–59.

Turner, R. K., Georgiou, S. and Fisher, B. 2008. Valuing ecosystem services: the case of multifuncional wetlands. Routledge, London and Sterling. 229 pp.

UN - United Nations 2015. Draft outcome document of the United Nations summit for the adoption of the post-2015 development agenda. *Sixty-ninth session of the General Assembly of the United Nations*, New York. 35 pp.

UN - United Nations, Department of Economic and Social Affairs, Population Division 2017. World population prospects: the 2017 revision, key findings and advance tables. *Working Paper No. ESA/P/WP/248*. 46 pp.

UNDP - United Nations Development Programme 2016. Human development report: human development for everyone. 271 pp.

Vences, M., Wollenberg, K. C., Vieites, D. R. and Lees, D. C. 2009. Madagascar as a model region of species diversification. *Trends in Ecology and Evolution* 24, 8: 456–465.

Villamagna, A. M. and Murphy, B. R. 2010. Ecological and socio-economic impacts of invasive water hyacinth (*Eichhornia crassipes*): a review. *Freshwater Biology* 55, 2: 282–298.

Villamagna, A. M., Murphy, B. R., and Karpanty, S. M. 2012. Community-level waterbird responses to water hyacinth (*Eichhornia crassipes*). *Invasive Plant Science and Management* 5, 3: 353–362.

Virah-Sawmy, M., Ebeling, J., Taplin, R. 2014. Mining and biodiversity offsets: a transparent and science-based approach to measure "no-net-loss". *Journal of Environmental Management* 143, 61–70.

Waheduzzaman, W., As-Saber, S. and Binte Hamid, M. 2018. Elite capture of local participatory governance. *Policy and Politics* 46, 4: 645–662.

Wallace A. P. C. 2012. Understanding fishers' spatial behavior to estimate social costs in local conservation planning [dissertation]. *Imperial College London*. 333 pp.

Wood, A. P., Dixon A. and McCartney, M. 2013. People-centred wetland management. In: *Wetland management and sustainable livelihoods in Africa*. A. P. Wood, A. Dixon and M. McCartney (eds.), pp 1–42. Routledge, London and New York. 142 pp.

World Bank 2014. Prosperity for all / ending extreme poverty: a note for the World Bank Group Spring Meetings 2014. License: Creative Commons Attribution — NonCommercial — NoDerivatives 3.0 IGO (CC BY-NC-ND 3.0 IGO), *World Bank*, Washington, DC. 30 pp.

World Bank 2018a. *World development indicators database. Country profile: Madagascar*. http://databank.worldbank.org/data/views/reports/reportwidget.aspx?Report_Name=CountryProfile&Id=b450fd57&tbar=y&dd=y&inf=n&zm=n&country=MDG. March 03, 2018.

World Bank 2018b. *Population estimates and projections*. https://datacatalog.worldbank.org/dataset/population-estimates-and-projections. March 03, 2018.

Yoder, A. D. and Nowak, M. D. 2006. Has vicariance or dispersal been the predominant biogeographic force in Madagascar? Only time will tell. *Annual Review of Ecology, Evolution, and Systematics* 37, 405–431.

Young, H. G., Razafindrajao, F. and Lewis, R. E. 2013. Madagascar's wildfowl (Anatidae) in the new millennium. *Wildfowl* 63, 63: 5–23.

Young, H. G., Young, R. P., Lewis, R. E., Razafindrajao, F., Bin Aboudou, I. A. et al. 2014. Patterns of waterbird diversity in central western Madagascar: where are the priority sites for conservation? *Wildfowl* 64, 64: 35–53.

Zhu, A. 2017. Rosewood occidentalism and orientalism in Madagascar. *Geoforum* 86: 1–12.

APPENDIX

Appendix 1. Mean ($\bar{x}$), standard deviation (SD) and range (Min., Max.) of the water parameters at the three study sites with different level of degradation (Vohimarina, D1 = low; Andreba, D2 = intermediate; Anororo, D3 = high). Presented are data measured within the vegetation during the rainy season (surface water and deep water) determined during four periods a day: 7000–1000h, 1000–1300h, 1300–1600h and 1600–1900h. Asterisks shown with the values of the surface water indicate statistically significant differences between surface water of sampled marsh vegetation and open water (n= 112, Table 3.1). *A*sterisks presented with the values of the deepwater indicate statistically significant differences between deep water of sampled marsh vegetation and open water (n = 112) (significance level: $p \leq 0.05$ = *, $p \leq 0.01$ = **, $p \leq 0.001$ = ***). (**Chapter 3**)

		Water parameters	D1 (n= 32)				D2 (n= 32)				D3 (n= 32)			
			$\bar{x}$	SD	Min.	Max.	$\bar{x}$	SD	Min.	Max.	$\bar{x}$	SD	Min.	Max.
Surface water (0–10 cm)	Rainy season	Conductivity (µS cm^{-1})	64	4,7	39	68	83	12,7	67	124	51	8,8	38	77
		DO (mg L^{-1})	4.6**	0,9	2,9	6,1	3,0	1,7	0,7	8,0	3,1	2,3	0,5	11,0
		DO (%)	61*	12,4	40	86	44	26	10,1	118	42	32	6,5	154
		pH	7,3	0,4	6,8	8,2	6,4	0,1	6,1	6,7	6,3	0,3	5,9	7,2
		Temp (°C)	26.4***	0,9	24,3	28,7	29,9	2,2	27,1	34,5	26,2	1,2	24,4	28,9
		Max. Water level (cm)	201*	29	130	225	168***	17,2	150	200	185	23	130	200
		Light (lux)	313*	344	3,6	1250	26***	28	0,0	114	171***	498	0,0	2653
Deep water (150 cm)		Conductivity (µS cm^{-1})	65*	2,7	61	78	103*	10,3	80	117	50	6,3	41	60
		DO (mg L^{-1})	4.3***	1,0	2,4	5,9	1,9	0,4	0,7	2,7	2.6*	0,8	1,7	4,8
		DO (%)	57***	13,6	31	79	26	6,0	8,3	37	35	11,5	23	64
		pH	7,2	0,4	6,0	8,2	6,3	0,1	6,1	6,4	6,3	0,1	6,0	6,6
		Temp (°C)	25.5**	0,4	24,6	26,2	26,8	0,5	26,0	28,2	25,1	0,6	23,8	26,4
		Max. Water level (cm)	202*	29	130	225	168***	17,2	150	200	185	23	130	200
		Light (lux)	0,0	0,0	0,0	0,0	1,2	4,8	0,0	24	0,0	0,0	0,0	0,0

Appendix 2. Mean ($\bar{x}$), standard deviation (SD), and range (Min., Max.) of the water parameters measured within the open water at Vohimarina (D1 = low-degraded) during the four daily periods (0700–1000h, 1000–1300h, 1300–1600h and 1600–1900h). (**Chapter 3**)

		Water parameters	D1 (n= 20)															
			7000–1000h				1000–1300h				1300–1600h				1600–1900h			
			$\bar{x}$	SD	Min.	Max.	$\bar{x}$	SD	Min.	Max.	$\bar{x}$	SD	Min.	Max.	$\bar{x}$	SD	Min.	Max.
Surface water (0–10 cm)	Dry season	Conductivity (µS cm^{-1})	83	13,0	68	117	82	15,5	69	131	76	7,5	65	89	78	10,6	68	105
		DO (mg L^{-1})	5,4	1,3	1,8	6,9	5,2	1,9	0,1	7,4	4,7	1,3	1,0	6,1	4,6	1,5	0,5	6,1
		DO (%)	73	17,5	24	96	73	27	1,2	99	68	18,8	10	89	65	22	7,2	86
		pH	6,8	0,3	5,6	7,3	6,9	0,2	6,6	7,2	6,9	0,2	6,6	7,3	6,8	0,1	6,6	7,0
		Temp (°C)	27,3	3,3	21,9	34,5	30,8	3,1	26,5	36,4	31,4	2,0	28,2	34,5	29,0	1,4	27,3	31,1
		Max. Water level (cm)	11,2	4,7	0,5	20	11,2	4,7	0,5	20	11,6	4,5	1,0	20	12,7	4,7	3,0	23
		Light (lux)	1100	733	135	2458	906	684	85	2839	1225	756	109	2430	444	294	46	1078
	Rainy season	Conductivity (µS cm^{-1})	65	4,1	64	81	65	1,0	62	67	64	1,2	63	67	63	1,9	60	68
		DO (mg L^{-1})	4,6	0,6	3,9	6,1	5,0	0,6	4,1	6,3	5,6	0,4	4,9	6,4	5,8	0,4	5,3	6,6
		DO (%)	60	7,6	44	76	66	7,5	54	81	75	5,7	67	89	76	5,6	68	85
		pH	7,1	0,3	6,5	7,7	7,3	0,2	6,9	7,6	7,5	0,3	7,2	8,2	7,6	0,4	7,2	8,3
		Temp (°C)	25,3	0,7	24,0	26,7	25,5	0,4	24,9	26,2	26,3	0,9	25,1	29,1	25,7	1,1	24,5	28,8
		Max. Water level (cm)	205	7,1	195	220	205	7,1	195	220	205	7,1	195	220	205	7,1	195	220
		Light (lux)	671	353	157	1531	589	583	10,0	1779	601	324	95	1418	258	227	24	776
Deep water (150 cm)	Rainy season	Conductivity (µS cm^{-1})	65	1,6	63	69	63	1,7	58	66	64	0,6	63	65	64	0,4	63	64
		DO (mg L^{-1})	5,1	0,9	3,2	6,8	5,2	0,7	4,1	6,5	5,6	0,6	4,4	6,6	5,9	0,4	4,7	6,7
		DO (%)	68	9,9	47	89	69	8,1	54	84	75	7,3	58	88	79	5,8	64	88
		pH	7,1	0,3	6,5	7,7	7,3	0,2	6,9	7,6	7,5	0,3	7,1	8,2	7,6	0,4	7,1	8,3
		Temp (°C)	24,5	0,4	23,8	25,0	25,0	0,3	24,4	25,7	25,5	0,3	24,9	25,8	25,4	0,6	24,4	26,6
		Max. Water level (cm)	205	7,1	195	220	205	7,1	195	220	205	7,1	195	220	205	7,1	195	220
		Light (lux)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Appendix 3. Mean ($\bar{x}$), standard deviation (SD), and range (Min., Max.) of the water parameters measured within the open water at Andreba (D2 = intermediate-degraded) during the four daily periods (0700–1000h, 1000–1300h, 1300–1600h and 1600–1900h). (**Chapter 3**)

		Water parameters	D2 (n= 20)															
			7000–1000h				1000–1300h				1300–1600h				1600–1900h			
			$\bar{x}$	SD	Min.	Max.	$\bar{x}$	SD	Min.	Max.	$\bar{x}$	SD	Min.	Max.	$\bar{x}$	SD	Min.	Max.
Surface water (0–10 cm)	Dry season	Conductivity (µS cm^{-1})	99	15,7	70	123	100	23	67	150	94	17,4	70	134	99	24	70	156
		DO (mg L^{-1})	4,3	2,3	0,3	7,7	3,4	2,2	0,1	7,6	3,3	1,6	0,7	6,0	3,6	1,4	0,9	5,7
		DO (%)	57	33	1,9	107	49	33	1,6	135	50	24	6,8	97	52	22	10,3	89
		pH	7,0	0,5	6,3	7,9	6,7	0,3	6,2	7,4	6,8	0,2	6,4	7,1	6,7	0,3	6,2	7,7
		Temp (°C)	27,9	3,2	21,3	32,5	32,8	4,9	25,8	40,8	33,1	4,5	27,2	41,3	29,6	2,5	25,4	32,7
		Max. Water level (cm)	2,8	1,8	1,0	6,5	2,1	1,3	1,0	5,0	3,3	2,5	1,0	10,0	3,9	3,0	1,0	10,0
		Light (lux)	277	215	14,3	766	384	261	48	936	463	304	27	1272	179	179	22	699
	Rainy season	Conductivity (µS cm^{-1})	86	11,1	71	109	81	8,2	69	95	80	8,7	67	93	79	9,9	66	94
		DO (mg L^{-1})	1,4	0,8	0,2	3,0	3,2	1,6	0,7	6,6	4,7	2,0	1,0	7,5	4,3	2,0	1,2	6,8
		DO (%)	22	17,1	2,3	82	46	23	10,0	98	71	33	14,1	117	62	30	15,8	103
		pH	6,3	0,1	6,1	6,5	6,3	0,1	6,2	6,6	6,5	0,1	6,3	6,7	6,5	0,1	6,3	6,8
		Temp (°C)	26,9	0,7	26,0	28,3	29,9	2,3	26,2	34,9	31,3	2,8	26,9	35,2	30,4	2,3	27,1	35,3
		Max. Water level (cm)	182	9,4	170	205	182	9,4	170	205	182	9,4	170	205	182	9,4	170	205
		Light (lux)	98	74	10,0	242	245	180	2,4	525	158	144	0,0	448	94	104	0,0	364
Deep water (150 cm)	Rainy season	Conductivity (µS cm^{-1})	100	10,8	80	122	97	10,4	74	112	91	11,0	75	110	94	11,9	76	117
		DO (mg L^{-1})	1,9	0,3	1,4	2,4	1,9	0,4	1,2	2,6	2,1	0,3	1,5	2,5	2,3	0,3	1,7	3,1
		DO (%)	26	4,0	18,2	33	27	5,1	16,6	33	29	4,4	19,1	35	31	4,9	23	43
		pH	6,2	0,1	6,1	6,4	6,3	0,1	6,1	6,4	6,3	0,1	6,2	6,4	6,3	0,1	6,2	6,6
		Temp (°C)	26,2	0,3	25,8	27,1	27,0	0,6	26,2	28,0	27,4	0,5	26,6	28,2	26,7	0,6	26,0	28,1
		Max. Water level (cm)	182	9,4	170	205	182	9,4	170	205	182	9,4	170	205	182	9,4	170	205
		Light (lux)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	15,4	30	0,0	99

Appendix 4. Mean ($\bar{x}$), standard deviation (SD), and range (Min., Max.) of the water parameters measured within the open water at Anororo (D3 = highly-degraded) during the four daily periods (0700–1000h, 1000–1300h, 1300–1600h and 1600–1900h). (**Chapter 3**)

		Water parameters	D3 (n= 20)															
			7000–1000h				1000–1300h				1300–1600h				1600–1900h			
			$\bar{x}$	SD	Min.	Max.	$\bar{x}$	SD	Min.	Max.	$\bar{x}$	SD	Min.	Max.	$\bar{x}$	SD	Min.	Max.
Surface water (0–10 cm)	Dry season	Conductivity (µS cm^{-1})	88	14	67	109	89	14	65	105	87	14,8	62	102	91	16	65	116
		DO (mg L^{-1})	5,3	1,1	2,3	7,0	6,9	0,9	4,9	7,9	6,9	1,2	4,0	8,0	6,3	0,6	5,1	7,4
		DO (%)	69	14,0	30	90	98	11,4	70	114	107	16,5	58	123	93	8,8	72	106
		pH	6,8	0,3	6,1	7,1	7,0	0,2	6,5	7,4	7,2	0,3	6,5	7,6	7,1	0,2	6,8	7,4
		Temp (°C)	24,5	0,7	23,2	25,6	29,5	1,4	26,9	32,4	33,5	2,1	30,2	36,8	31,6	1,9	29,6	35,0
		Max. Water level (cm)	14,5	3,7	7,0	21	14,0	4,0	7,0	21	14,5	5,5	8,0	22	15,7	4,2	8,0	22
		Light (lux)	1271	669	39	2792	2793	1289	173	6350	2541	1602	122	5140	701	610	23	1991
	Rainy season	Conductivity (µS cm^{-1})	51	6,1	43	62	50	5,6	41	61	50	6,3	34	62	49	6,6	31	60
		DO (mg L^{-1})	2,0	1,2	0,5	4,2	2,6	1,1	1,0	4,6	3,4	1,0	1,1	4,9	4,6	1,5	2,2	8,0
		DO (%)	26	16,2	6,7	52	32	14,7	13	60	46	12,7	15	66	62	22	25	110
		pH	6,3	0,3	6,0	7,0	6,3	0,2	6,0	6,6	6,4	0,2	6,1	6,9	6,6	0,2	6,2	7,0
		Temp (°C)	25,0	0,6	24,4	26,5	25,3	1,0	24,3	28,8	26,9	1,3	25,0	29,4	25,7	1,3	23,5	27,8
		Max. Water level (cm)	195	5,0	185	200	195	5,0	185	200	195	5,0	185	200	195	5,0	185	200
		Light (lux)	849	1038	8,5	3680	1374	1772	20	6830	1768	1658	5,2	5160	272	334	0,0	989
Deep water (150 cm)	Rainy season	Conductivity (µS cm^{-1})	50	5,1	43	58	50	5,2	43	59	50	5,5	42	59	50	5,8	41	59
		DO (mg L^{-1})	2,9	1,0	1,9	5,0	3,1	1,0	2,0	4,9	3,0	0,9	1,7	5,0	3,4	0,9	2,1	5,0
		DO (%)	40	13,1	25	65	40	13,3	25	64	40	11,3	22	62	44	11,4	26	63
		pH	6,4	0,2	6,0	6,9	6,3	0,2	6,1	6,7	6,4	0,2	6,1	6,8	6,5	0,2	6,3	7,0
		Temp (°C)	24,6	0,6	22,4	25,3	25,0	0,6	24,0	26,8	25,6	0,6	24,7	26,8	24,7	0,7	23,6	25,7
		Max. Water level (cm)	195	5,0	185	200	195	5,0	185	200	196	5,4	185	200	195	5,0	185	200
		Light (lux)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Appendix 5. Plant species, growth forms, site specific and plant species cover in % (= mean, SD = standard deviation, Max. = maximal cover; D = degradation level; 1 = low (Vohimarina), 2 = intermediate (Andreba), 3 = high (Anororo); n.i. = unidentified species; H+ = helophyte with a height ≥ 2m, H- = helophyte with a height < 2m, Hy = hydrophyte, P = pleustophytes, E = endemic, I = invasive, NT = naturalized, NV = native). (**Chapter 3**)

Family	Species	Growth form	Status	Cover (%) D1 (n= 61)			D2 (n= 59)			D3 (n= 55)			Total (n= 175)		
				$\bar{x}$	SD	Max.	$\bar{x}$	SD	Max.	$\bar{x}$	SD	Max.	$\bar{x}$	SD	Max.
Amaranthaceae	*Alternanthera sessilis*	H-	NT	0	0,3	2	0	0,3	2	0	0	0	0	0,2	2
Asteraceae	*Ethulia conyzoides*	H-	NT	0	0	0	0,2	1,3	10	0	0	0	0,1	0,8	10
Commelinaceae	*Commelina aff. lyallii*	H-	-	0	0	0	0	0,3	2	0,1	0,4	2	0	0,3	2
Convolvulaceae	*Argyreia vahibora*	H+	E	1,2	4,1	20	2,4	9,9	50	3	11,2	70	2,2	8,8	70
Convolvulaceae	*Ipomoea aquatica*	H-	-	0	0	0	0,1	0,6	4	0	0	0	0	0,3	4
Cyperaceae	*Cyperus madagascariensis*	H+	E	0,1	0,6	4	0	0,3	2	2,2	7,1	30	0,7	4,1	30
Cyperaceae	*Cyperus pectinatus*	H-	-	0	0	0	0	0,3	2	0	0	0	0	0,2	2
Cyperaceae	*Oxycaryum cubense*	H-	-	0	0	0	0,1	0,6	4	0,1	0,5	2	0,1	0,4	4
Cyperaceae	*Pycreus mundtii*	H-	-	0	0	0	1,0	2,2	10	0,8	2,8	20	0,6	2,1	20
Menyanthaceae	*Nymphoides indica*	Hy	NV	0,2	1,3	10	0	0	0	0	0	0	0,1	0,8	10
Nymphaeaceae	*Nymphaea nouchali*	Hy	NV	8,6	20,4	80	0,1	0,5	4	0	0	0	3	12,6	80
Onagraceae	*Ludwigia perennis*	H-	NV	0	0	0	0,2	1,3	10	0,2	1,3	10	0,1	1,1	10
Onagraceae	*Ludwigia stolonifera*	H-	NV	3,1	11,5	70	8,7	15	80	6,9	11	40	6,2	12,8	80
Phytolaccaceae	*Phytolacca* sp.	H-	-	0	0	0	2,2	10,3	60	0	0	0	0,8	6,1	60
Poaceae	*Echinochloa pyramidalis*	H-	NV	23,5	29,8	97,5	5,1	7,9	40	4,9	8,8	50	11,5	20,7	97,5
Poaceae	*Echinochloa stagnina*	H-	NV	0,2	0,8	4	0,3	0,7	2	0	0	0	0,2	0,6	4
Poaceae	*Leersia hexandra*	H-	NV	0	0,3	2	0,5	1,9	10	0,7	2,8	20	0,4	1,9	20
Poaceae	*Oryza sativa*	H-	NT	0	0	0	0,2	0,8	4	0	0,3	2	0,1	0,5	4
Poaceae	*Phragmites australis*	H+	NT	2,4	13,1	90	2,9	6,8	30	3,4	13,6	80	2,9	11,5	90
Polygonaceae	*Persicaria glabra*	H-	NT	0,5	1,9	10	1,3	3,5	20	4,8	11,6	60	2,1	7,1	60
Pontederiaceae	*Eichhornia crassipes*	P	I	0,4	1,5	10	24,4	31,1	90	53	41	97,5	25	36,1	97,5
Salviniaceae	*Salvinia* spp.	P	NV/I	1,3	3,4	20	31,4	32,5	97,5	14,4	25,8	100	15,6	26,8	100

Appendix 6. Shown are means and standard deviation of the vertical vegetation density at the three sites; D = degradation level, 1 = low (Vohimarina), 2 = intermediate (Andreba), 3 = high (Anororo). (**Chapter 3**)

Height (cm)	Density (%) D1 (n= 61)		D2 (n= 59)		D3 (n= 55)	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
0–3	25,9	26,9	51,3	34,0	76,5	31,2
3–5	21,9	24,9	39,3	35,1	67,8	38,6
5–10	22,5	25,9	32,4	35,8	67,4	42,3
10–20	23,7	26,5	29,3	35,5	61,9	39,2
20–30	24,0	28,0	26,5	35,8	56,3	40,7
30–50	22,9	28,3	22,6	34,7	45,4	40,5
50–100	10,1	16,4	12,9	25,1	26,4	32,1
100–150	1,6	6,5	6,6	18,2	6,4	12,6
150–200	0,7	3,6	3,7	11,6	2,6	7,0
200–300	0,7	3,4	1,3	4,0	0,7	2,4
300–500	0,2	0,9	0,3	1,1	0,0	0,0

Appendix 7. Shown are means and standard deviation of the vertical vegetation density of the lake shore vegetation at the three sites; D = degradation level, 1 = low (Vohimarina), 2 = intermediate (Andreba), 3 = high (Anororo). (**Chapter 3**)

Height (cm)	Density (%)					
	D1 (n= 36)		D2 (n= 35)		D3 (n= 34)	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
0–3	33,2	27,3	53,5	36,1	78,3	29,2
3–5	31,1	25,0	42,1	37,9	68,8	37,9
5–10	33,0	27,0	38,7	39,1	71,0	44,6
10–20	36,9	27,2	39,1	38,9	67,6	38,6
20–30	38,3	28,7	36,6	39,3	64,9	38,0
30–50	37,1	29,4	32,9	39,9	58,3	37,2
50–100	17,0	18,5	19,4	29,9	39,6	33,8
100–150	2,7	8,4	10,1	22,8	9,9	15,0
150–200	1,3	4,7	5,6	14,5	4,3	8,5
200–300	1,3	4,4	1,7	4,5	1,2	3,0
300–500	0,3	1,2	0,4	1,2	0,0	0,0

Appendix 8. Shown are means and standard deviation of the vertical vegetation density on the open water at the three sites; D = degradation level, 1 = low (Vohimarina), 2 = intermediate (Andreba), 3 = high (Anororo). (**Chapter 3**)

Height (cm)	Density (%)					
	D1 (n= 25)		D2 (n= 24)		D3 (n= 21)	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
0–3	15,3	22,8	48,0	31,2	73,6	34,7
3–5	8,7	18,0	35,0	31,0	66,2	40,7
5–10	7,3	14,6	23,1	28,9	61,4	38,7
10–20	4,8	6,2	15,0	24,0	52,8	39,4
20–30	3,3	3,2	11,7	23,6	42,4	41,9
30–50	2,4	2,9	7,6	17,1	24,6	37,5
50–100	0,3	0,9	3,4	10,3	5,0	10,6
100–150	0,0	0,0	1,4	4,5	0,6	1,4
150–200	0,0	0,0	0,9	4,1	0,0	0,0
200–300	0,0	0,0	0,6	3,1	0,0	0,0
300–500	0,0	0,0	0,2	1,0	0,0	0,0

Appendix 9. Adjustments of the modified TWINSPAN Analyses following Roleček et al. (2009). (**Chapter 4**)

Pseudospiecies cutlevels	9
Values of cutlevels	0, 1, 2, 4, 10, 20, 40, 60, 80
Minimum group size	3
Number of clusters	6
Dissimilarity index	Whittaker´s beta diversity

Appendix 10. Questionnaires. **(Chapter 4)**

Questionnaire 1 (addressed to local stakeholders that are at least theoretically involved in the management and direct conservation practices in Park Bandro)

Part A (general information)

1. Age____ Profession_____ Sex w ☐ m ☐

2. Do you belong to one of the following groups?

   ☐ Tourist guide in Park Bandro

   ☐ Tourist boat driver in Park Bandro

   ☐ Boat rental for tourist tours

   ☐ MWC employee

   ☐ MWC member

   ☐ VOI employee

   ☐ Other:______________

Part B (financial income and resource use)

3. Did you use the area of Park Bandro before its foundation?

   Yes ☐ No ☐

   If yes, for what?

   ☐ Fishing

   ☐ Fowling

   ☐ Rice cultivation

   ☐ Harvesting *Cyperus papyrus* subsp. *madagascariensis* for construction material

   ☐ Harvesting *Cyperus papyrus* subsp. *madagascariensis* for handicrafts

   ☐ Collecting medicinal plants

   ☐ Collecting plants as fodder

   ☐ Other: _____________

4. Do you have financial losses after the foundation of Park Bandro?

Yes ☐ No ☐

If yes, which revenues were lost or decreased after the foundation of Park Bandro? Revenues from:

☐ Fishing

☐ Fowling

☐ Rice cultivation

☐ Harvesting *Cyperus papyrus* subsp. *madagascariensis* for construction material

☐ Harvesting *Cyperus papyrus* subsp. *madagascariensis* as handicraft material

☐ Collecting medicinal plants

☐ Collecting plants as fodder

☐ Other: _____________

How much income did you have less since the foundation of Park Bandro?

On average in a month (MGA): ________ On average in a year (MGA): ___________

5. Do you have financial income generated by Park Bando?

Yes ☐ No ☐

If yes, what are the sources of your income?	What is your average income generated by Park Bandro?	
	month (MGA)	year (MGA)
☐ Tourist guide in Park Bandro	_________	_________
☐ Tourist boat driver in Park Bandro	_________	_________
☐ Boat rental for tourist tours	_________	_________
☐ Fishing inside Park Bandro	_________	_________
☐ Fowling inside Park Bandro	_________	_________

☐ Rice cultivation inside Park Bandro	________	________
☐ Harvesting *Cyperus papyrus* subsp. *madagascariensis* for construction material in Park Bandro	________	________
☐ Harvesting *Cyperus papyrus* subsp. *madagascariensis* as handicraft material	________	________
☐ Collecting medicinal plants	________	________
☐ Collecting plants as fodder	________	________
☐ Other: ____________	________	________

6. Do you use Park Bandro for personal needs (without having financial revenues)?

Yes ☐ No ☐

If yes, what kind of use/ how do you use the Parks resources?

- ☐ Fishing
- ☐ Fowling
- ☐ Rice cultivation
- ☐ Harvesting *Cyperus papyrus* subsp. *madagascariensis* for construction material
- ☐ Harvesting *Cyperus papyrus* subsp. *madagascariensis* as handicraft material
- ☐ Collecting medicinal plants
- ☐ Collecting plants as fodder
- ☐ Other: ____________

7. How many persons in Andreba do benefit, in your opinion, from Park Bandro?

____

Part C (understanding and acceptance)

8. Have you ever seen the 'Bandro'?

Yes ☐ No ☐

If yes, when have you seen the 'Bandro' for the last time at Lake Alaotra?

last week ☐ last month ☐ last year ☐ __years ago ☐

9. Have you ever seen the 'Bandro' inside Park Bandro?

Yes ☐ No ☐

If yes, when have you seen the 'Bandro' for the last time inside Park Bandro?

last week ☐ last month ☐ last year ☐ __years ago ☐

10. Is it allowed to enter Park Bandro and to use the resources inside (for fishing, rice cultivation etc.)?

A ☐ It is allowed to enter Park Bandro and to use the resources inside

B ☐ It is allowed to enter Park Bandro but forbidden to use the resources inside

C ☐ It is forbidden to enter Park Bandro and to use the resources inside

If **B or C**, please give your reasons not entering park Bandro and using its resources?

☐ I am afraid of penalties (police)

☐ I am afraid of other villagers watching me and speaking badly about me

☐ I have no reason to enter park Bandro

☐ I do not enter Park Bandro because it is a protected area

11. Is Park Bandro important for the village of Andreba (it´s inhabitants)?

☐ Yes, for the whole village

☐ Yes, for some people

☐ No, it is not important for the village but does not represent a disadvantage for the village

☐ No, Park Bandro represents a disadvantage for the village

If yes, why? ________________

If yes, for which group of people does Park Bandro represent an advantage? ___________

If no, why? _________________

If no, for which group of people does Park Bandro represent a disadvantage? _________

12. Is Park Bandro important for you?

Yes ☐ No ☐

If yes, why? ________________

If no, why? _________________

13. Did you know that Park Bandro is a protected area?

Yes ☐ No ☐

If yes, what is the reason to place the area under protection?

☐ I do not know

☐ Other reason: ________________

Questionnaire 2 (addressed to local stakeholders without a direct involvement with park management but who might be affected by the park since they are working within its perimeter)

Part A (general information)

1. Age____ Profession_____ Sex w ☐ m ☐

Part B (financial income and resource use)

2. Did you use the area of Park Bandro before its foundation?

   Yes ☐ No ☐

   If yes, for what?

   ☐ Fishing

   ☐ Fowling

   ☐ Rice cultivation

   ☐ Harvesting *Cyperus papyrus* subsp. *madagascariensis* for construction material

   ☐ Harvesting *Cyperus papyrus* subsp. *madagascariensis* for handicrafts

   ☐ Collecting medicinal plants

   ☐ Collecting plants as fodder

   ☐ Other: _____________

3. Do you have financial losses after the foundation of Park Bandro?

   Yes ☐ No ☐

   If yes, which revenues were lost or decreased after the foundation of Park Bandro? Revenues from:

   ☐ Fishing

   ☐ Fowling

   ☐ Rice cultivation

   ☐ Harvesting *Cyperus papyrus* subsp. *madagascariensis* for construction material

   ☐ Harvesting *Cyperus papyrus* subsp. *madagascariensis* as handicraft material

☐ Collecting medicinal plants

☐ Collecting plants as fodder

☐ Other: _____________

How much income did you have less since the foundation of Park Bandro?

On average in a month (MGA): __________ On average in a year (MGA): __________

4. Do you have financial income generated by Park Bando?

Yes ☐ No ☐

If yes, what are the sources of your income?	What is your average income generated by Park Bandro? month (MGA)	year (MGA)
☐ Fishing inside Park Bandro	_________	_________
☐ Fowling inside Park Bandro	_________	_________
☐ Rice cultivation inside Park Bandro	_________	_________
☐ Harvesting *Cyperus papyrus* subsp. *madagascariensis* for construction material in Park Bandro	_________	_________
☐ Harvesting *Cyperus papyrus* subsp. *madagascariensis* as handicraft material	_________	_________
☐ Collecting medicinal plants	_________	_________
☐ Collecting plants as fodder	_________	_________
☐ Other: _____________	_________	_________

5. Do you use Park Bandro for personal needs (without having financial revenues)?

   Yes ☐ No ☐

   If yes, what kind of use/ how do you use the Parks resources?

   ☐ Fishing

   ☐ Fowling

   ☐ Rice cultivation

   ☐ Harvesting *Cyperus papyrus* subsp. *madagascariensis* for construction material

   ☐ Harvesting *Cyperus papyrus* subsp. *madagascariensis* as handicraft material

   ☐ Collecting medicinal plants

   ☐ Collecting plants as fodder

   ☐ Other: _____________

6. How many persons in Andreba do benefit, in your opinion, from Park Bandro?

   ____

Part C (understanding and acceptance)

7. Have you ever seen the 'Bandro'?

   Yes ☐ No ☐

   If yes, when have you seen the 'Bandro' for the last time at Lake Alaotra?

   last week ☐ last month ☐ last year ☐ __years ago ☐

8. Have you ever seen the 'Bandro' inside Park Bandro?

   Yes ☐ No ☐

   If yes, when have you seen the 'Bandro' for the last time inside Park Bandro?

   last week ☐ last month ☐ last year ☐ __years ago ☐

9. Is it allowed to enter Park Bandro and to use the resources inside (for fishing, rice cultivation etc.)?

A ☐ It is allowed to enter Park Bandro and to use the resources inside

B ☐ It is allowed to enter Park Bandro but forbidden to use the resources inside

C ☐ It is forbidden to enter Park Bandro and to use the resources inside

If **B or C**, please give your reasons not entering park Bandro and using its resources?

☐ I am afraid of penalties (police)

☐ I am afraid of other villagers watching me and speaking badly about me

☐ I have no reason to enter park Bandro

☐ I do not enter Park Bandro because it is a protected area

10. Is Park Bandro important for the village of Andreba (it´s inhabitants)?

☐ Yes, for the whole village

☐ Yes, for some people

☐ No, it is not important for the village but does not represent a disadvantage for the village

☐ No, Park Bandro represents a disadvantage for the village

If yes, why? ________________

If yes, for which group of people does Park Bandro represent an advantage? ___________

If no, why? _________________

If no, for which group of people does Park Bandro represent a disadvantage? _________

11. Is Park Bandro important for you?

Yes ☐ No ☐

If yes, why? ________________

If no, why? _________________

12. Did you know that Park Bandro is a protected area?

Yes ☐ No ☐

If yes, what is the reason to place the area under protection?

☐ I do not know

☐ Other reason: ________________

Appendix 11. Table shows the recorded plant species in Park Bandro (PB) and the outside area (OA), the mean ± SE for vegetation cover (%), maximum vegetation height (cm) and species cover (%), the significance values (p) for statistical comparisons between Park Bandro (BP) and the outside area (OA) as well as the species distribution and status (E = endemic, I = invasive, N = naturalized, NA = native, X = status unconfirmed, -- = assignment to distribution status group was not possible on generic level; letters in brackets indicate data source: a = Kull et al. 2012, b = Tropicos Database, c = African Plant Database). (**Chapter 4**)

		RA (N= 21)		PB (N= 21)			
		$\overline{X}$	SE	$\overline{X}$	SE	*p*	
	Vegetation Cover (%)	76	4.8	92	1.4	0.005 **	
	Cover Open Water (%)	21	4.7	4.8	1	0.001 ***	species
	Cover Other (%)	1.9	1	1	0.5	0.246	distribution
	Vegetation Height (Max. in cm)	250	37	365	13	0.023 *	/status
Amaranthaceae	*Alternanthera sessilis*	0	0	0	0	2.000	N [(a)]
Araceae	*Thyphonodorum lindleyanum*	0	0	0.2	0.1	0.162	NA [(b)]
Araliaceae	*Hydrocotyle* sp.	0	0	0	0	0.341	NA [(b)]
Asteraceae	*Emilia adscendens*	0	0	0	0	0.341	E [(b)]
	Ethulia conyzoides	0.2	0.1	0	0	0.040 *	N [(a)]
Commelinaceae	*Commelina* sp.	0.4	0.2	0.7	1.1	0.347	--
Convulvulaceae	*Argyreia vahibora*	0.3	0	31.7	6	≤ 0.001 ***	E [(b)]
	Cuscuta campestris	0	0	0.5	0.5	0.162	N [(a,b)]
	Ipomoea aquatica	0.6	0.5	0.1	0.1	0.180	X [(b)]
Cyperaceae	*Cyperus papyrus* subsp. *madagascariensis*	1.2	0.9	50	6.3	≤ 0.001 ***	NA [(b)]
	Cyperus pectinatus	0.4	0.2	0	0	0.146	NA [(b)]
	Cyperus prolifer	0.1	0.1	0	0	0.341	NA [(b)]
	Oxycaryum cubense	0	0	0	0	0.341	NA [(b)]
	Pycreus mundtii	4	2.4	0.5	0.2	0.048 *	X [(c)]
	Pycreus polystachyos	0.2	0.1	0	0	0.040 *	NA [(b)]
Fabaceae	*Aeschynomene elaphroxylon*	0.1	0.1	2.6	1.4	0.311	N [(a)]
	Aeschynomene sensitiva	0	0	0	0	0.341	X [(a)]
Lentibulariaceae	*Utricularia inflexa*	0.1	0.1	0	0	0.341	NA [(b)]
	Utricularia sp.	0.1	0.1	0	0	0.081	--
Nympheaceae	*Nymphaea lotus*	1.7	0.8	0	0	0.002 **	NA [(b)]
Onagraceae	*Ludwigia perennis*	1.7	0.5	0.7	0.2	0.064	NA [(b)]
	Ludwigia adscendens subsp. *diffusa*	2.5	1.0	1.3	0.3	0.705	NA [(c)]
Phytolaccaceae	*Phytolacca* sp.	0	0	0	0	0.341	--
Poaceae	*Echinochloa pyramidalis*	28	6.2	1.8	1.0	≤ 0.001 ***	NA [(b)]
	Leersia hexandra	5.4	1.8	2.6	0.8	0.144	NA [(b)]
	Oryza longistaminata	2.6	1.7	0	0	0.040 *	NA [(b)]
	Oryza sativa	0.7	0.5	0	0	0.040 *	N [(b)]
	Panicum hymeniochilum	0.2	0.1	2.6	1.5	0.228	NA [(b)]
	Phragmites australis	5.3	3.3	6.8	3.5	0.306	N [(b)]
Polygonaceae	*Persicaria glabra*	9.1	3.3	8.7	2.6	0.337	N [(b)]
Pontederiaceae	*Eichhornia crassipes*	9.7	4.1	1.9	0.5	0.044 *	I [(b)]
Salviniaceae	*Salvinia* spp.	13.8	3.4	1.7	0.7	0.001 ***	I [(b)]
Thelypteridaceae	*Cyclosorus interruptus*	4.3	4.3	11.3	4.5	0.008 **	NA [(b)]

Appendix 12. Table shows the mean ± SE for vertical density (%) and the significance values (p) for statistical comparisons between Park Bandro (PB) and the outside area (OA). (**Chapter 4**)

	RA (N= 21)		PB (N= 21)		
	$\bar{x}$	SE	$\bar{x}$	SE	*p*
0-3 cm	81	5	85	3	0.758
3-5 cm	74	6	83	3	0.593
5-10 cm	65	7	80	3	0.267
10-20 cm	58	7	76	4	0.064
20-30 cm	46	6	72	4	0.005 **
30-50 cm	32	6	59	5	0.003 **
50-100 cm	15	5	44	5	≤ 0.001 ***
100-150 cm	1	0	26	5	≤ 0.001 ***
150-200 cm	0	0	12	3	≤ 0.001 ***
200-300 cm	0	0	4	1	≤ 0.001 ***
300- end	0	0	1	0	0.063

Appendix 13. Interviews performed with the Alaotran fishermen. Interviews comprise 41 questions and were performed with 117 fishermen at Lake Alaotra. **(Chapter 5)**

General information

1. **Age** ______
2. **Sex** ________ (w/m)
3. **Village** __________
4. **Years of fishing experience?** ______ (e.g. < 1 year; 15 years)

5. **Why did you become a fisherman?**

   ☐ Family tradition: we have always been a family of fishers

   ☐ It was my personal wish to become a fisherman

   ☐ I can earn money by fishery all the year

   ☐ Other reason: _____________

Example: ☒ Vovo ladina May – June, August - January; 200 St., 2 cm

6. **Which method/s do you use?**
   In which month (e.g. 2-6) do you use which method/s?
   How many gear items are you using (+ mesh size)

☐ Vovo ladina ___________________	☐ Fintana mandry or Lohamandry ______
☐ Vovo treoka___________________	☐ Fintana atsipy ____________________
☐ Vovo fil ______________________	☐ Fintana elice _____________________
☐ Sitra petit_____________________	☐ Tosika __________________________
☐ Sitra gand_____________________	☐ Valatany ________________________
☐ Harato fandrika ________________	☐ Ridrano _________________________
☐ Harato balle ___________________	☐ Leoka ___________________________
☐ Harato tarika or Dakadaka _______	☐ Jinjira ___________________________
☐ Épervier or Harato atsipy ________	☐ Mangodo _________________________
☐ Haratolava/Haratobe ___________	☐ Dadevo __________________________
☐ Ramangoaka__________________	☐ Other: ___________________________
☐ Misaka _______________________	

7. **Why do you use this method?** ***In case there are different answers for different methods used, please note them on the backside and just add the right number, e.g. Vovo fil=*** **1), 4)**

- ☐ Catch rates: this method has high catch rates
- ☐ Tradition: this method is tradition in my family and we own the material (gear)
- ☐ Gear maintenance is easy
- ☐ Gear can be made by myself
- ☐ Gear usability: I am competent with this method
- ☐ No material (gear) is needed for this method (e.g. tosika)
- ☐ Other: ___________________

Travel time, fishing time and fishing location

8. **Where do you fish using which method/s?**
marsh = ____
lake-marsh edge = ____
lake = ____
next to the harbor = ____

9. **How much time (hours or days per week) do you....**

...need to travel from landing site to fishing location (travel time - both ways)? (hours per day)
Wet season _______ Dry season _______

...spend with fishing each day (only fishing time, no travel time)? (hours per day)
Wet season _______ Dry season _______

...need to repair your fishing gear? ____________ (days per month)

...need to prepare your fishing gear for each fishing trip? ____________ (hours per fishing trip)

...need for selling the fish that you catch?

- ☐ Yes, it needs_____ (minutes/hours for each catch)
- ☐ No, I do not sell my catch since I use it for my own family

10. **How many days do you spend with fishing each week?**
Wet season _______ Dry season _______

11. **Where do you store your gear/s during the year?**
- ☐ In the house
- ☐ It is placed on the lake (I only take some at home for reparation)
- ☐ Other: _______________________

Livelihood (Sources of income)

12. How big is your household (people) / family income per month (Ariary)? _______ /____________

13. Do you fish in a group? (e.g. for sitra grand) If YES, how many are you? __________

14. How much money (Ariary) do you (only you alone, without group partners) earn per month by fishing? _____________

This is enough to:

☐ support me (and my family) with food.

☐ cope with financial bottlenecks (e.g. bad harvests, fishing closure, illnesses)

☐ improve the own economic situation (e.g. investment in new facilities, material, school costs)

15. How do you earn your livelihood?

A ☐ Full-time fisherman: I earn my livelihood solely by fishing.

Why do you earn your livelihood solely by fishing?

☐ Thanks to fishery, I earn enough money for my (and my families) livelihood

☐ I do not earn enough money for my (and my families) livelihood but I´ve no possibility to practice another occupation because:

☐ I have no money to buy the required material or tools

☐ I have not learned another occupation

☐ I want to stay in my village but there are no other sources of income (in my village)

☐ Other reason: ____

B ☐ Part-time fisherman: In the past I earned my livelihood solely by another occupation. Today I work additionally as a fisher to earn enough money for my livelihood.

Which occupation was sufficient in the past to support your livelihood?

☐ Cultivation of_____________ (e.g. beans, vary jebo, vary jebo and onions)

☐ Breeding of ______________ (e.g. zebu)

☐ Selling of_________________

☐ Working for a daily salary as______________

☐ Other: ___________________

Why is this occupation no longer sufficient to support your livelihood?

☐ I earn less money due to the poorer harvests

☐ I earn less money due to ____

☐ Other:____

Since when do you work additionally as a fisher? __________________ (e.g. < 1 year; 15 years)

C ☐ **Part-time fisherman: In the past I earned my livelihood solely by fishing.** Today I have another occupation besides the fishery.

Since when do you practice another occupation besides fishery? ________(e.g. < 1 year; 15 years)

Why is fishing no longer sufficient to support your livelihood?

☐ I earn less money due to declining catches

☐ I earn less money due to lower sales prices

☐ I earn less money due to ____

☐ Other: ____

16. Please note again which activities do you make a living during each season:

Indicate the proportion of work time (e.g. 80% fishing, 20 % rice cultivation)

Estimate income for activities other than fishing

DRY SEASON			
OCCUPATION	**YES (X)**	**Days per week**	**INCOME**
Fishery			
Rice cultivation			Ariary or tonnes per
Breeding			Animal: Number of animals
Shop/store			Ariary per
Work for someone else			Ariary per
Other:			Ariary per

WET SEASON			
OCCUPATION	**YES (X)**	**Days per week**	**INCOME**
Fishery			
Rice cultivation			Ariary or tonnes per
Breeding			Ariary per
Shop/store			Ariary per
Work for someone else			Ariary per
Other:			Ariary per

17. Do you know....

the fishing closure (15.11 – 15-01)? ☐ YES ☐ NO

the no-take zones for fishing (restricted areas)? ☐ YES ☐ NO

18. Do you fish...

during the fishing closure? ☐ YES ☐ NO

in no-take zones? ☐ YES ☐ NO

19. Do you have alternative sources of income during the fishing closure?

☐ YES: ______________ ☐ NO

20. Does the fishing closure have positive or negative impacts on you?

☐ Positive impacts: _______________ ☐ Negative impacts: _______________

21. Do your leave your fishing gear on the lake/inside the marshes during the fishing closure?

☐ YES ☐ NO

<u>**Fishery – Investments**</u>

22. How much cost a fishing pirogue? ________________ Ariary (it is a pirogue for ___person/s)

23. What is the biggest barrier when you someone wants to become a fisherman?

☐ To get a pirogue for fishing

If YES, why? ____________________ (e.g. lack of money to buy or material to build a pirogue)

☐ To have enough money to buy the material for my gear (e.g. for vovo, filets, fintana...)

☐ To have enough time to make my gear (e.g. vovo, filets, fintana...)

☐ To find a fishing ground to place the traps or nets (or fintana)

If YES, why? _____________________ (e.g. already assigned to people)

☐ To learn to fish

☐ Other: ____

24. Do you repair your fishing material (e.g. vovo, filets, fintana...) on your own?

☐ YES ☐ NO, because____

If YES, why?

☐ Because it is much cheaper to repair it on my own

☐ Other: ____

25. Do you make your fishing material (e.g. vovo, filets, fintana...) on your own?

☐ YES ☐ NO, because____

If YES, why?

☐ Because it is much cheaper to make it on my own

☐ Other: ____

26. Who owns the pirogue you are using for fishing?

☐ It´s my pirogue (pirogue of my direct family: my wife, parents of my wife or my parents)

☐ The pirogue belongs to my bigger family (aunt, uncle, cousin...)

☐ The pirogue belongs to another family and I have to rent it for money

How many days a week do you rent it? ________________

How much Ariary does it cost per day? ________________ (AR)

☐ Other: ____

27. How do you regulate the use of the pirogue?

☐ I do not have to share the pirogue with other people

☐ I have to share the pirogue with other people

If you have to share it:

With how many persons do you share it? ___________ (number of people)

How do you share it? Explain: ________________ (e.g. each of the 2 persons uses the pirogue half the night)

28. How do you regulate the use of fishing grounds? (read the answers)

☐ Fishing grounds are traditionally owned by a family

☐ You own a fishing ground by frequent use or by building a hamatra

☐ Fishing grounds are allocated by authorities: ______________ (e.g. fokontany, village elders)

☐ Fishing grounds are flexible and change every day

☐ Fishing grounds rotate based on the following system: (explain on the backside of the paper)

29. Are there still “free” fishing grounds left?

☐ Yes many, even close to the village.

☐ Yes many, but they are far away from the village.

☐ Most of the fishing grounds are assigned to certain people/families nowadays.

☐ No fishing grounds are left

30. What are the biggest problems for the fisheries at Lake Alaotra?

☐ People, stealing the material (vovo, nets...)

☐ People, stealing the pirogues

☐ Declining catches

☐ Smaller fishes than in earlier days

☐ Smaller fishing grounds due to an increasing number of fishermen

☐ Fight for fishing grounds due to an increasing number of fishermen

☐ Lack of pirogues

☐ Lack of material

☐ Many methods are illegal

☐ Time/Duration of fishing closure

☐ The price for fish on the local market is bad

☐ Collectors (e.g. from Tana) offer bad prices for fish

☐ Collectors (e.g. from Tana) don´t come here anymore

☐ Low water levels forces fisherman to travel far to fishing ground

☐ Other: ____

31. Which problems of the fisheries at Lake Alaotra mainly affect you?

☐ People, stealing the material (vovo, nets...)

☐ People, stealing the pirogues

☐ Declining catches

☐ Smaller fishes than in earlier days

☐ Smaller fishing grounds due to an increasing number of many fishermen

☐ Fight for fishing grounds due to an increasing number of many fishermen

☐ Lack of pirogues

☐ Lack of material

☐ The method I use is illegal

☐ Time/Duration of fishing closure

☐ The prices for fish on the local marked is pad

☐ Collectors (e.g. from Tana) offer bad prices for fish

☐ Collectors (e.g. from Tana) don´t come here anymore

☐ Low water levels forces fishermen to travel far to fishing grounds

☐ Other: ____

32. Did the number of fishermen increased during the last years?

☐ No, the number of fishermen is more or less the same

☐ Yes, the number of fishermen has increased

If YES*, *who are the new fishermen?

☐ Mainly young people from our village, that wants to become fisherman. (personal wish)

☐ Mainly, people from our village that become fisherman because their income from other sources is not enough anymore

☐ Mainly, immigrants from other regions

☐ Other: ____________________________

33. Is the fishery in recent times a popular occupation for people of the Alaotra region?

☐ No, it is not, because:

☐ Yes, it is. The main reason/s is/are:

☐ Fishes can be caught all over the year

☐ People do not have to own land for being a fisher

☐ The material is not too expensive (pirogues can be shared)

☐ Other: ____

34. Did the fish catches changed during the last time? (If Yes, why?)

☐ No

☐ Yes:

☐ I catch less species

☐ The selling prices are lower for fish

☐ The fishes are smaller

☐ I catch less fish

☐ Other: ___________________________

<u>**Climate**</u>

35. When did the rainy season start in your childhood?

_________ (month)

_________ (your age when you were a kid, e.g. 8 years old)

36. Did the rainy season postponed during the last time?

☐ No, it did not change

☐ Yes, it is earlier

☐ Yes, it is delayed

If YES (earlier or delayed),

When starts the rainy season nowadays? __________ (month, e.g. in Nov; between Nov-Jan)

Since how many years is the rainy season regularly postponed? __________ (number of years)

Does the postponed rainy season have any impact on your livelihood?

☐ No

☐ Yes

If YES, which of your works is affected by the postponed rainy season? (e.g.: no rain)

☐ Agriculture, because: _______________________________________

☐ Fishery, because: ____

☐ Other work/s: ____________, because: ________________________

37. In case you are cultivating rice or vegetables:
In which month do you nowadays regularly start to plant?

Kind of rice/vegetable 1): _______________ (e.g. vary toana or jebo, beans)
____________ (month: sowing the seeds (rice, vegetables)
____________ (month: planting the rice)

Kind of rice/vegetable 2): _______________ (e.g. vary toana or jebo, beans)
____________ (month: sowing the seeds (rice, vegetables)
____________ (month: planting the rice)
In case you (your family) is planting more than 2 plants, please write down each additional cultivated vegetable on the back side, number it (vegetable 2) and add the information for sowing and planting (month).

Future

38. Do you (your family) notice changes in the Alaotra region? (If Yes, what changes?)

- ☐ **No, there are no changes in the Alaotra region**
- ☐ **Yes, changes like:**
  - ☐ Yield reduction (agriculture)
  - ☐ Less catches (fishery)
  - ☐ Smaller fishes
  - ☐ Conflicts between: ______________________
  - ☐ Less income
  - ☐ More people in the Alaotra region
  - ☐ Increased number of fishers
  - ☐ Other: ________________________________

If, YES
What are the reasons for the changes mentioned before?
(*reasons have to be given only for changes mentioned before*)

Yield reduction (agriculture): _______________________________

Less catches (fishery): ____________________________________

Smaller fishes: ____

Conflicts: ____

Less income: ____

More people in the Alaotra region: __________________________

Increased number of fishers: _______________________________

Other: ____

If YES, are you (your family) affected by one or more of the following developments?

Yes, we are affected by:

- ☐ Yield reduction (agriculture)
- ☐ Less catches (fishery)
- ☐ Smaller fishes
- ☐ Conflicts
- ☐ Less income

- ☐ More people in the Alaotra region
- ☐ Increased number of fishers
- ☐ Other: ________________________________

☐ **No, we are not affected.**

39. Can you imagine that the fisheries in Lake Alaotra will ever collapse and your catch per day would be less than 500g?

- ☐ Yes, I think this will happen during the next ________years
- ☐ Yes, I think this might happen once, but not within the next ______years.
- ☐ No, I think a collapse of the fisheries is unlikely to happen.
- ☐ No, I think a collapse of the fisheries will never happen

40. Do you want your son to become a fisher?

Yes, because: ________________________ No, because: ____________________________

41. Which expectations do you have for your professional future? (open question)

____
____
____
____

Thank you very much!

Appendix 14. Results from the interviews with Alaotran fishers (n = 117) showing the number of respondents and the percentage (%) of respondents for each question. **(Chapter 5)**

		No. of respondents	Percentage (%) of respondents
Q2	**Sex**		
	f	**0**	**0**
	m	**117**	**100**
Q3	**Village**		
	Andreba	**28**	**24**
	Vohimarina	**30**	**26**
	Anororo	**30**	**26**
	Andilana Sud	**29**	**25**
Q5	**Reasons for becoming a fisherman (n= 117, responses= 121)**		
	Personal wish	**32**	**27**
	Family tradition	**29**	**25**
	Easiness	**23**	**20**
	No education needed	10	9
	No financial investment needed	2	2
	No spatial effort needed	7	6
	Other	4	3
	Livelihood security	**18**	**15**
	Additional job/income	7	6
	Poverty	2	2
	Lack of alternatives	9	8
	Earn money all the year	**15**	**13**
	Other	**4**	**3**
Q6	**Used fishing method/gear (n=117, responses=124)**		
	Gill net	**24**	**21**
	Cast net	**12**	**10**
	Trap	**70**	**60**
	Line & hook	**11**	**9**
	Hand method	**3**	**3**
	Dip net	**1**	**0.9**
	Seine net	**1**	**0.9**
	Enclosure (plant or mud enclosure)	**1**	**0.9**
	Spear	**1**	**0.9**
Q7	**Reasons for using a fishing method/gear (n= 117, responses= 126)**		
	Easiness	**75**	**64**
	Gear maintenance	33	28
	Gear usability	21	18
	Gear can be made by myself	1	0.9
	No material (gear) needed	4	3
	No hard work	13	11
	Gear specific non-financial advantages	3	3
	Financial benefits	**23**	**20**
	High catch rates	18	15
	Other gear specific advantages	2	2
	No specification	3	3
	Family tradition	**12**	**10**
	Allows additional occupation	**14**	**12**
	Other	**2**	**2**
Q10 1	**Fishing days during the dry season (n=117)**		
	1	-	-
	2	**2**	**2**
	3	**5**	**4**
	4	**8**	**7**
	5	**10**	**9**
	6	**16**	**14**
	7	**70**	**60**
	Does not fish during the dry season	**5**	**4**
	No answer	**1**	**0.9**

		No. of respondents	Percentage (%) of respondents
Q10 2	**Fishing days during the wet season (n=117)**		
	1	**1**	**0.9**
	2	**1**	**0.9**
	3	**4**	**3**
	4	**4**	**3**
	5	**14**	**12**
	6	**19**	**16**
	7	**64**	**55**
	Does not fish during the wet season	**7**	**6**
	No answer	**3**	**3**
Q14	**Income is enough to (n=117)**		
	Support me/my family with food	**29**	**25**
	Cope with financial bottlenecks	**64**	**55**
	Improve my economic situation	**24**	**21**
Q15	**Livelihood strategies (n=117)**		
	Part-time fisherman: fishery as second occupation	**68**	**58**
	Part-time fisherman: fishery as first occupation	**29**	**25**
	Full-time fisherman	**20**	**17**
Q15A	**Reasons for being a full-time fisher (n=20)**		
	Supports livelihood	**3**	**15**
	Does not support livelihood but there is no possibility to practice another occupation because:	**17**	**85**
	No fields	8	40
	No money to buy equipment	7	35
	Lack of education	1	5
	Other reasons	1	5
Q15B 1	**Occupation, sufficient in the past to support livelihood (n= 68, responses=74)**		
	Agriculture	**60**	**88**
	Vary toana (rain-fed rice cultivation)	34	50
	Vary jebo (rice cultivation inside the marshes during the dry season)	6	9
	Vary an-tanety (rain-fed rice cultivation on the hills)	3	4
	Vegetables	12	18
	No specification	5	7
	Breeding	**5**	**7**
	Daily salary	**4**	**6**
	Seller	**3**	**4**
	Other	**2**	**3**
Q15B 2	**Reasons why former occupation is no longer sufficient to support livelihood (n=68, responses= 75)**		
	Less income due to:		
	Social reasons: children (sharing income or agricultural land)	**6**	**9**
	Economic reasons	**41**	**60**
	Decreasing yield	19	28
	Too few fields	11	16
	Lacking equipment	10	15
	Broader economic reasons	**20**	**29**
	Decreasing income/ lack of money	6	9
	Single occupation is insufficient	6	9
	Livelihood insecurity	8	12
	Other	**8**	**12**
Q15B 3	**Number of years working additionally as a fisher (n= 68)**		
	0-9	**13**	**19**
	10-19	**20**	**29**
	20-29	**12**	**18**
	30-39	**10**	**15**
	40-49	**4**	**6**
	50-59	**3**	**4**
	No answer	**6**	**9**

	No. of respondents	Percentage (%) of respondents
Q15C 1 Reasons of fishing to be no longer sufficient for livelihood (n= 29, responses= 32)		
Economic reasons	**11**	**38**
Declining catches	8	28
Lacking equipment	3	10
Broader economic reasons	**11**	**38**
Decreasing income/lack of money	5	17
Single occupation is insufficient	3	10
Livelihood insecurity	3	10
Other	**4**	**14**
No answer	**6**	**21**
Q15C 2 Years of practicing another occupation besides fishery (n=29)		
0-9	**21**	**72**
10-19	**5**	**17**
20-29	**2**	**7**
30-39	**-**	**-**
40-49	**1**	**3**
Q23 Barriers to become a fisherman (n= 117 interviewees, responses= 128)		
Getting a pirogue	**9**	**8**
To have money to buy the material for gear	**48**	**41**
Learn to fish/knowing how to fish	**15**	**13**
Hard and frightening work	**8**	**7**
Laziness	**5**	**4**
Other	**8**	**7**
Not necessary to fish because	**35**	**30**
Enough inome/money/fields/work on the land	29	25
Good equipment	1	1
Other jobs	5	4
Q30 Biggest problems for the fisheries at Lake Alaotra (n= 117, responses= 347)		
Social conflicts and criminal behavior	**98**	**84**
People, stealing the gear	71	61
People, stealing the fishes	9	8
People, stealing the pirogues	5	4
Disturbing/destroying fishing gear	13	11
Declining catches	**78**	**67**
Smaller fishes	**37**	**32**
Smaller fishes than in earlier days	12	10
Destruction of small fishes	25	21
Smaller fishing grounds	**14**	**12**
Increasing number of fishermen	6	5
Invasive plant species	7	6
No specification	1	0.9
Fight for fishing grounds	**3**	**3**
Lack of pirogues	**6**	**5**
Lack of equipment	**43**	**37**
Many methods are illegal and/or destroy the environment	**6**	**5**
Fishing closure	**6**	**5**
Time/duration	4	3
Spatial restrictions	1	0.9
No specification	1	0.9
The prices for fish on the local market is bad	**6**	**5**
Collectors offer bad prices for fish	**1**	**0.9**
Low water levels force fishermen to travel far to fishing ground	**24**	**21**
Weather & Climate	**13**	**11**
Other	**12**	**10**

		No. of respondents	Percentage (%) of respondents
Q31	**Biggest problems for the fishery at Lake Alaotra (n= 117, responses= 241)**		
	Social conflicts and criminal behavior	**63**	**54**
	People, stealing the gear	28	24
	People, stealing the fishes	16	14
	People, stealing the pirogues	1	0.9
	Disturbing/destroying fishing gear	18	15
	Declining catches	**74**	**63**
	Smaller fishes	**8**	**7**
	Smaller fishes than in earlier days	3	3
	Destruction of small fishes	4	3
	Smaller fishing grounds	**7**	**6**
	Increasing number of fishermen	1	0.9
	Invasive plant species	6	5
	Fight for fishing grounds	**4**	**3**
	Lack of pirogues	**3**	**3**
	Lack of equipment	**37**	**32**
	Illegal methods	**5**	**4**
	The method I use is illegal	3	3
	People use illegal methods	2	2
	The prices for fish on the local market is bad	**3**	**3**
	Collectors offer bad prices for fish	**1**	**0.8**
	Low water levels force fishermen to travel far to fishing ground	**14**	**12**
	Weather & Climate	**13**	**11**
	Other	**9**	**8**
Q33	**Recent popularity of fishery as occupation in the Alaotra region and its reasons (n=117, responses= 121)**		
	No:	**-**	**-**
	Yes, because:	**117**	**100**
	Fishes can be caught all over the year	52	44
	Many methods and easy money	10	9
	Many big and/or valuable fish	33	28
	Less fish/wealth than in former times	19	16
	Other	6	5
	No specification	1	1
Q34	**Changes in fish catches (n= 117, responses= 132)**		
	I catch less species	**8**	**7**
	The selling prices are lower for fish	**4**	**3**
	The fishes are smaller	**9**	**8**
	Less fish	**100**	**85**
	I catch less fish	95	81
	Destruction of small fish	5	4
	Fishers do not respect the law (e.g. illegal methods)	**3**	**3**
	Weather problems	**5**	**4**
	Other	**3**	**3**
Q35	**Start of rainy season in childhood (n=117)**		
	Childhood 4-19 years ago (n= 31)		
	Before December	**18**	**58**
	December or later	**13**	**42**
	Childhood 20-39 years ago (n=60)		
	Before December	**43**	**72**
	December or later	**17**	**28**
	Childhood 40-59 years ago (n=26)		
	Before December	**25**	**96**
	December or later	**1**	**4**
Q36 1	**Postponement of rainy season (n=117)**		
	No, it did not changed	**3**	**3**
	Yes, it is delayed	**114**	**97**
Q36 2	**Impact of posponed rainy season on livelihood (n=114)**		
	No	**2**	**2**
	Yes	**112**	**98**

		No. of respondents	Percentage (%) of respondents
Q36 3	**Work affected by postponed rainy season (n=112, responses= 123)**		
	Agriculture	**39**	**35**
	Fishery	**80**	**71**
	Other work/s	**4**	**4**
	Reasons for work being affected by the postponed rainy season? (n=112, responses=126)		
	Agriculture, because:		
	Delayed activities/yield	**27**	**24**
	Bad yield	**10**	**9**
	Dryness	**3**	**3**
	Fishery, because:		
	Delayed activities/income (e.g. later increase of water level)	**36**	**32**
	No or less fish catch (e.g. low water level)	**40**	**36**
	Smaller fishes	**5**	**4**
	Other	**5**	**5**
Q38 1	**Do you (your family) notice changes in the Alaotra region? (n= 117)**		
	No	**4**	**3**
	Yes	**113**	**97**
Q38 2	**Changes in the Alaotra region (n=113, responses= 154)**		
	Yield reduction (agriculture)	**13**	**12**
	Less catches (fishery)	**64**	**57**
	Smaller fishes	**6**	**5**
	Conflicts	**10**	**9**
	Less income	**7**	**6**
	More people in the Alaotra region	**3**	**3**
	Increased number of fishers	**6**	**5**
	Criminal behavior	**9**	**8**
	Climate variations	**18**	**16**
	Positive changes	**6**	**5**
	Environmental destruction	**4**	**4**
	Other	**8**	**7**
Q38 3	***If , YES***		
	Reasons for the changes mentioned before (n=113, responses= 172)		
	Livelihood insecurity	**17**	**15**
	Climate variations/lack of rain/delayed rainy season	**44**	**39**
	Less yield/catch/income/ poverty	**16**	**14**
	Environmental degradation	**26**	**23**
	Criminality/llegal methods/weak government	**16**	**14**
	No or less small fishes	**26**	**23**
	Jealousy	**5**	**4**
	Increased number of fishermen/population	**8**	**7**
	Other reasons	**14**	**12**
Q40	**Son should become a fisher (n=117)**		
	Yes	**33**	**28**
	No	**83**	**71**
	No answer	**1**	**0.9**
	Yes, because (n=33, responses= 34)		
	Follow family tradition/help father	**17**	**52**
	School failure	**6**	**18**
	Better than no job/small reliable income	**5**	**15**
	Poverty/no money for school	**6**	**18**
	No, because (n= 83, responses= 86)		
	Workload	**15**	**18**
	Hard/difficult work	9	11
	Increasingly hard/difficult work	6	7
	Livelihood insecurity	**53**	**64**
	Alternative to unemployment	**15**	**18**
	Other	**3**	**4**

		No. of respondents	Percentage (%) of respondents
Q41	**Expectations for professional future (n=117, respnses= 126)**		
	Negative expectations	**99**	**85**
	No hope	26	22
	No hope but find alternatives	33	28
	Some hope, if something happens (e.g. fishers organization, more rain, respecting the law, more small fishes)	18	15
	Hope for children (education)	5	4
	Government has to take action	12	10
	No specification	5	4
	No expectations/fatalistic	**13**	**11**
	Positive expectations	**9**	**8**
	Other	**5**	**4**

		Median	Range
Q1	**Age**	**40**	**17-71**
Q4	**Years of experience**	**17**	**1-52**

Appendix 15. Fishing trip duration. Median time for travel, fishing and total trip (hh:mm) indicated by Alaotran fishers from Andilana Sud, Anororo, Vohimarina and Andreba for the dry season (DS) and wet season (WS). Fishing times between seasons were compared with Mann-Whitney U tests.
(Chapter 5)

Time	Median (range)	Dry season (range)	Wet season (range)	Statistical significance (WS vs. DS)
Time to travel to and from landing site to fishing ground (n_{WS}= 106, n_{DS}= 110)	1:00 (0:02-5:30)	1:30 (0:10-5:30)	1:00 (0:02-5:30)	p = 0.000
Time spend fishing (n_{WS}= 105, n_{DS}= 105)	2:30 (0:30-10:00)	2:30 (0:30-10:00)	3:00 (0:30-6:30)	p = 0.927
Total trip duration (n_{WS}= 104, n_{DS}= 104)	3:42 (0:35-12:00)	4:00 (1:20-12:00)	3:30 (0:35-10:00)	p = 0.111

Acknowledgement

An dieser Stelle möchte ich mich bei den vielen Menschen bedanken, die mich auf dem Weg zu dieser Doktorarbeit in vielfältiger Weise unterstützt haben.
In den letzten Jahren habe ich unglaublich viel über die Interaktion zwischen Menschen und Natur in den Tropen gelernt. Für die Möglichkeit dieses spannende und lehrreiche Thema zu untersuchen und die zahlreichen Erfahrungen zu sammeln, möchte ich mich hier von ganzem Herzen bei meinen Betreuern Prof. Jasmin Mantilla-Contreras und Dr. Torsten Richter bedanken. Liebe Jasmin, danke, dass du dich für diese Projektidee eingesetzt hast und für deine fortwährende Unterstützung während der gesamten Doktorarbeit. Lieber Torsten, danke für die zahlreichen Anregungen zur Datenerhebung und -auswertung und die offenen, direkten (und teilweise sehr amüsanten) Worte.

J'aimerais tout particulièrement remercier Bernard Aimé Rajaonarivelo et Lala Nomenjanahary Elysé, mes assistants de terrain. L'expression "assistant" ne rend pas cependant justice à vos contributions à ce travail. Pour moi, vous étiez bien plus que des assistants. Par le moyen de tes connaissances, Bernard, j'ai pu réellement comprendre l'interaction de la vie de la population avec la nature. Ta persévérance et de ton soutien pendant les dures heures de travaux sur terrain ont ontribué de manière significative à leur réussite. Lala, merci pour to aide et support pendant ces périodes. Ton savoir sur la nature locale et ton engagement constant et fiable m'ont été d'une grande aide. Je me souviendrai longtemps des innombrables heures passées sur le lac avec vous deux, de votre bonne humeur, des vos histoires, de vos chansons ("*katsakatsa* ...") et de vos nombreuses tentatives pour m'apprendre la langue malgache. Merci pour vos soutiens!
Un grand merci également aux habitants d'Andreba, Anororo et Vohimarina, particulièrement la famille de M. Laza d'Anororo et la famille de Mr. Manana et Freddo de Vohimarina. Merci de m'avoir acceuilli si chaleureusement pendant mon séjour à Madagascar et de m'avoir permis de participer à vos vies quotidiennes. Je tiens également à remercier Narindra d'Andreba. Tes plats délicieux ont souvent compensé mes longues et épuisantes journées de travail.
Je voudrais remercier le VOI et le Fokontany d'Andreba, Anororo et Vohimarina pour leur coopération. Je souhaite également remercier la *Direction régionale des ressources halieutiques et de la pêche*, la *Circonscription des eaux et forêts* et le *Ministère de l'environnement, de l'écologie et des forêts* pour leur soutien pendant mon travail. Des remerciements spéciaux vont également aux employés de *Durrell Wildlife Conservation Trust* à Ambatondrazaka. Merci surtout pour le support logistique.

Jonah Ratsimbazafy, je te remercie pour ta supercooperation avec notre projet et les nombreuses excursions que nous avons organisées ensemble. Ta personnalité unique, ton enthousiasme contagieux et ton engagement incessant pour la nature de Madagascar m'ont beaucoup impressioné et m'ont permis de nouveau de prendre conscience de la valeur de notre travail.

Ich danke allen meinen Kollegen und Kolleginnen aus dem Fachbereich 4 für die wunderbare Zusammenarbeit, die gute Atmosphäre und den Spaß, den wir in den letzten vier Jahren hatten. Sie haben mich alle unterstützt und meine Arbeit an der Universität Hildesheim zu einer schönen Zeit gemacht.

Der Kommission und den Gutachtern danke ich vielmals für die Bewertung meiner Arbeit.

Ganz großer Dank geht auch an den "Stifterverband für die Deutsche Wissenschaft" für die finanzielle Unterstützung des AMBio Projektes. Erst dank solch großzügiger Förderung ist es unserem Projetmitgliedern möglich gewesen, bestehende Wissenslücken zu schließen und somit einen Beitrag zum Schutz der Biodiversität am Alaotra See zu leisten.

Bei Lotte bedanke mich für die zahlreichen Stunden, die sie über meinen Manuskripten und am Telefon mit mir verbracht hat. Liebe Lotti, danke, danke, danke. Es hätte niemand besser machen können!

Meinen Freunden möchte ich für die Geduld mit mir danken, insbesondere im letzten Jahr, in dem ich wahrscheinlich fast gänzlich von der Bildfläche verschwunden war.

Meiner Familie, insbesondere meiner Mutter und meinem Vater, möchte ich dafür danken, dass sie mein Interesse an der tropischen Natur und Kultur geweckt haben und dieses Interesse trotz etwaiger Schwierigkeiten immer bedingungslos unterstützt haben. Bei meinen Geschwistern möchte ich mich für den Zuspruch bedanken, den sie mir während der gesamten Zeit der Promotion gegeben haben.

Lieber Tsiry, vielen Dank für deine Geduld und Liebe während der gesamten letzten Jahre. Danke dafür, dass du an meiner Seite warst und bist! Du bist wahrlich der beste „*side-effect*" mit dem die Promotion mich überraschen konnte.

Eidesstattliche Versicherung

Ich, Pina Lena Lammers, versichere, dass ich die Abhandlung selbständig und ohne unerlaubte Hilfe verfasst habe, die benutzten Hilfsmittel vollständig angegeben und die Zitate und Quellen wissenschaftlich korrekt ausgewiesen habe und, dass die Anforderungen an die Abhandlung nach der Zulassung zur Promotion erfüllt sind.

Hildesheim den 28.11.2018

Pina Lammers